Universidade de Lisboa

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Diet and feeding ecology of the Antarctic Skua in New Island, Falkland Islands

Tatiana de Mendonça Alves

Mestrado em Ecologia Marinha

Dissertação orientada por:

Professor Doutor Paulo Catry |ISPA
Professor Doutor José Pedro Granadeiro |FCUL

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“Uma onda beijou-me os pés...”

Porque estás e estarás sempre em tudo o que faço.

Amar-te-ei para sempre, avó.

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Resumo

Os moleiros são aves marinhas filogeneticamente relacionadas com as gaivotas (ordem: Charadriiformes), pertencentes à família Stercorariidae. Estas aves passam a maior parte do tempo no oceano, vindo a terra apenas com o intuito de se reproduzirem. Apresentam dimorfismo sexual invertido, sendo as fêmeas geralmente maiores que os machos. Estes animais são predadores generalistas, alimentando-se oportunisticamente das presas disponíveis e conhecidos por recorrer a técnicas de cleptoparasitismo. Em alguns locais, a sua alimentação durante a época reprodutora é distinta da do resto do ano, uma vez que durante este período estas aves dependem maioritariamente de recursos alimentares que não são estritamente oceânicos, e nestes casos, pouco se deslocam ao oceano.

O moleiro das Falkland (*Catharacta antarctica antarctica*) é uma subespécie do moleiro antártico (*C. antarctica*), endémica ao arquipélago das Falkland e um estudo recente mostrou que a sua principal população reprodutora se encontra em declínio. Essa escassez de dados é bem patente na ausência de informação tão básica como a caraterização morfológica das populações e diferenciação entre os sexos.

Atualmente, as técnicas mais fidedignas de sexagem de aves com baixo grau de dimorfismo sexual são técnicas moleculares. Estas podem, contudo, revelar-se um problema caso exista a necessidade de sexar grandes quantidades de amostras, uma vez que podem ser morosas e são, principalmente, de custo elevado. As funções discriminantes baseadas em dados biométricos constituem uma técnica que desde há muito é utilizada como método de determinação do sexo de diversas espécies de aves marinhas, quando estas não apresentam um dimorfismo sexual muito acentuado.

Também a dieta do moleiro das Falkland é mal conhecida. Uma das técnicas mais utilizadas para a caracterização de dieta das aves marinhas baseia-se na análise de regurgitações espontâneas e de restos de presas abandonados nos seus territórios. Mais recentemente, as técnicas de análise de isótopos estáveis ganharam popularidade, tornando-se uma ferramenta imprescindível para estudos de dieta, já que podem ser aplicados à cadeia trófica oferecendo informação sobre a dieta e, adicionalmente, sobre o nível trófico e o local onde a espécie estudada se alimenta.

O seguimento de aves através do uso de dispositivos de GPS permite-nos complementar informação sobre a ecologia trófica da espécie, possibilitando a identificação dos locais de alimentação das aves e os seus padrões de atividade. Algumas populações de moleiros antarticos defendem territórios alimentares em colónias de outras aves marinhas, como pinguins e corvos-marinhos, podendo este comportamento alimentar impactar a sua dieta.

Estes aspetos – a caracterização morfológica da população, e o estudo da dieta e comportamento alimentar - constituem o foco desta tese. O trabalho de campo para o presente estudo decorreu em New Island (51°43'S, 61°18'W), nas ilhas Falkland, entre novembro de 2014 e o final de fevereiro de 2015, englobando quase totalmente toda a época reprodutora destas aves. Esta ilha é o mais importante local de reprodução do moleiro das Falkland, e alberga também importantes populações de outras espécies de aves marinhas. Merece destaque a população de thin-billed prions

(*Pachyptila belcheri*) nidificante em NI, estimada em 2 milhões de pares de indivíduos e que constitui uma presa importante do moleiro das Falkland.

Para a base de dados de parâmetros morfométricos contribuíram observações obtidas durante este estudo, mas também as registadas em anos prévios, desde 2008. Os caracteres medidos em moleiros foram o comprimento de asa, o comprimento do bico, gónio, tarso e massa. Uma amostra de sangue foi recolhida em 24 moleiros e mantida em etanol (98%), sendo posteriormente utilizada em laboratório para sexagem dos indivíduos. O DNA foi extraído através do "EZNA™ Tissue DNA Kit", sendo de seguida amplificado e submetido a um processo de eletroforese para determinação do sexo através da observação de bandas. Os resultados da sexagem molecular foram utilizados para desenvolver uma função discriminante, a partir dos dados biométricos medidos no terreno. Esta função discriminante permitiu sexar corretamente 89.2% dos animais da amostra. É, assim, aconselhável utilizar técnicas moleculares ou observações diretas dos momentos de cópula para determinar com maior segurança o sexo de aves desta espécie.

De forma a caracterizar e descrever a dieta de moleiro das Falkland foram efetuadas visitas semanais a 49 territórios de reprodução, desde o início de janeiro até ao fim de fevereiro. As regurgitações e restos de presas encontradas nestes territórios foram recolhidas (para análise e também para evitar recontagem futura) e analisadas. A frequência de ocorrência foi calculada para os diferentes tipos de presas encontrados em regurgitações de skuas. Uma análise de componentes principais foi também utilizada para sumariar as presas encontradas, bem como para análise de variância (ANOVA) testando-se diferenças de valores de isótopos entre machos e fêmeas em diferentes territórios.

Para a utilização de dispositivos de GPS foram escolhidos 23 indivíduos na fase final de incubação. Os dispositivos foram colocados nas penas dorsais das aves, sendo recolhidos após 5 dias. No momento da recolha dos dispositivos, foi retirada e guardada a temperatura ambiente uma amostra de sangue para posterior análise isotópica. Esta análise foi feita no "Stable Isotopes and Instrumental Analysis Facility (SIIAF)" do Centro de Ecologia, Evolução e Alterações Ambientais da Universidade de Lisboa. Também foram efetuadas observações diretas de comportamento, em três áreas na principal colónia de aves marinhas onde os moleiros antárticos se alimentam, desde o início de janeiro até ao fim de fevereiro, num total de 5 horas semanais por área. Moleiros observados com comportamentos agonísticos para com conspecíficos e a capturar alimentos dentro de uma determinada zona foram considerados como defensores de territórios alimentares. Foram utilizados testes t de Student para comparar valores médios de diversas variáveis e correlações de Spearman para relacionar as diferentes variáveis recolhidas, tais como data de eclosão do primeiro ovo, sucesso reprodutor, distância entre ninhos e principal colónia de aves marinhas, valores de rácios de isótopos, frequências de ocorrência de principais presas e viagem de alimentação mais longa.

Foram identificadas duas fontes principais de alimento do moleiro das Falkland: as zonas de reprodução e de ninhos de thin-billed prion, e uma colónia de outras aves marinhas como albatrozes, pinguins e corvos-marinhos, a rookery. A análise de regurgitações e de restos de presas demonstrou que a principal presa do moleiro das Falkland, durante esta época reprodutora, foi o thin-billed prion representando 72.4% (n=1155) e 78.2% n=(2672) , respetivamente. Da análise supracitada demonstra-

se que existem diferenças nas dietas entre diferentes territórios, nomeadamente que aqueles que se encontram mais perto das colónias vizinhas de espécies de aves marinhas alimentam-se principalmente de ovos, lobster krill e crias de pinguins e corvos marinhos, enquanto que os restantes se alimentam maioritariamente de thin-billed prions. Infere-se que a localização do ninho influencia a dieta.

Não se observaram diferenças significativas entre as razões de isótopos estáveis de Carbono (Δ13C) e Azoto (Δ15N) entre machos e fêmeas. Contudo existem diferenças entre territórios, e os valores de ambos os isótopos foram tanto maiores quanto mais próximos os territórios de reprodução se encontravam de colónias vizinhas de espécies de aves marinhas. Observou-se uma correlação positiva dos valores de razões isotópicas de C e N com a presença de ovos e lobster krill nas dietas de moleiros, e negativa com a presença de thin-billed prions. A distância do ninho à principal área de alimentação (rookery ou prions) encontra-se positivamente correlacionada com a ocorrência de prions na dieta, e negativamente com a presença de lobster krill.

A informação obtida através do seguimento por GPS confirmou que o moleiro das Falkland raramente se desloca ao oceano para se alimentar durante a época reprodutora, possuindo quase exclusivamente atividade diurna.

Os moleiros que defendem territórios alimentares têm territórios de reprodução a uma curta distância. Os pares territoriais têm um sucesso reprodutor superior aos não territoriais, aproximadamente o dobro de crias vivas no fim da época reprodutora (1.25±0.87 e 0.68±0.63, respetivamente). No final desta época reprodutora, o sucesso reprodutor foi de aproximadamente 0.82 (±0.73) crias por casal, o que representa um aumento considerável desde o último estudo realizado com esta espécie (0.34).

O tipo de dieta parece não influenciar o sucesso reprodutor diretamente, estando este relacionado com a data de eclosão dos ovos de moleiro e com a presença de territórios alimentares. Assim, a presença contínua de alimento parece ser um factor mais importante do que o tipo de alimento obtido. O moleiro das Falkland apresenta uma dieta diferente de outras espécies anteriormente estudadas, mas a capacidade destes animais se adaptarem rapidamente a alterações na disponibilidade do alimento pode explicar este facto. Revela-se crucial o estudo de dietas de aves marinhas, dada a importância das informações que daí advêm na compreensão do funcionamento dos ecossistemas e na previsão de futuros impactamentos.

Palavras-chave: Falklands, skua, ecologia trófica, biometrias

Abstract

The Falkland skua is a poorly studied seabird, facing a sharp decline on its main breeding population. Few information is available about its biometries, and little is known about its diet and feeding behaviour during breeding season. We sexed a sample of 103 birds using molecular methods and used these data to derive a discriminant function based on biometric data (wing length, bill length, gonys, tarsus and mass), collected throughout different breeding seasons. Using within-pair comparisons, this discriminant function was able to correctly sex 89.2% of the birds in pairs. It is therefore advisable to use molecular analysis or direct observations of copulating behaviour to correctly sex this species. Pellet and prey remain were used to describe and characterise the diet of this seabird, and stable isotope analysis (Carbon and Nitrogen). We also deployed GPS loggers and carried out behaviour observations to obtain data on foraging behaviour. The main prey item in the diet of this species is the thin-billed prion, although rare foraging movements are performed during the night. Lobster krill and goose barnacles, along with eggs from seabirds, also constitute important prey items in their diet. Diets of skuas differed according to the location of their territories: skuas nesting near rookeries fed mainly on eggs, lobster krill and chicks of penguins and cormorants while skuas nesting far away from these areas fed mostly on thin-billed prions. Tracking data showed that Falkland skuas are mostly diurnal foragers, seldom moving during the night, and rarely performing long foraging trips to the ocean during breeding season. Some pairs hold feeding grounds in colonies of other seabirds, benefitting from higher breeding success when compared to those who do not. The breeding success does not seem to be directly correlated with the prevalence of particular prey items, but rather with the hatching date and existence of feeding territories defended by these pairs of skuas. The breeding success of the sampled population for the breeding season of 2014/2015 has also improved since the last published study.

Keywords: Falklands, skua, feeding ecology, biometries

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Chapter 1: General introduction

Skuas are marine birds that spend the majority of their time the sea, only coming to land for breeding purposes during the summer months. These birds belong to the order Charadriiformes, being closely related to gulls. Skuas are part of the Stercorariidae family, while gulls belong to the Laridae family (Furness 1987). Some authors defend that the Stercorariidae family should be classified as subfamily of the Laridae family (Moynihan 1959, Brooke 1978, Fain & Houde 2007). The phylogeny of the skuas is still under a lot of discussion since the molecular data presented by the work of Cohen et al (1997) was brought to light, but based on morphological and behavioural differences the Stercorariidae can be divided into two different genera, *Stercorarius* and *Catharacta*. The former genera consists of three small bodied skua species (Arctic skua – *S. parasiticus*, pomarine skua – *S. pomarinus* and long-tailed skua – *S. longicadus*), known as jaegers in American literature. These are known to breed at high northern latitudes and typically have elongated tail feathers and distinctive alternate plumage, being dark and barred while juveniles (Cohen *et al.* 1997). The *Catharacta* genera consists of four species (great skua – *C. skua*, south polar skua – *C. maccormicki*, Chilean skua – *C. chilensis* and Antarctic skua – *C. antarctica*), all of them larger than *Stercorarius* species. Five of them breed at high southern latitudes, and one in the northern hemisphere (great skua) (Furness 1987, Chu *et al.* 2009). The juveniles are not barred, and they do not have white-bellied plumage or long central tail feathers, in opposition to *Stercorarius* species. In terms of evolutionary history, it is thought that skuas originated from a common ancestral in the Northern hemisphere, later colonizing the Southern Hemisphere. The Northern hemisphere genus, *Stercorarius*, and the Southern hemisphere one, *Catharacta*, then differentiated, and the areas in North Atlantic were then later recolonized by an ancestor of the present great skua (Furness 1987, Cohen *et al*. 1997).

All skua species show sexual dimorphism, the females being larger than the males (Andersson 1999, Catry 1999), but this distinction is hard to perceive. Skuas have some characteristics in common with birds of prey, like reversed sexual dimorphism and sharp beaks and hooked claws (Furness 1987), which allow them to catch relatively large prey (Andersson 1999). They are opportunistic feeders, adapting themselves to the availability of prey and being able to actively prey on other animals (including other seabirds). This flexibility in terms of diet allows them to occupy diverse trophic niches and to adapt to changes in prey populations from year to year. These birds are also known for their kleptoparasitism behavior, which is particularly present for skuas of the *Stercorarius* genus (Chu *et al.* 2009). Skuas have different diets during breeding season than those during the year, relying more heavily on terrestrial food sources than ocean ones (Furness 1987).

Skuas are generally monogamous, tending to mate with the same individual over the course of years (Catry *et al.* 1997). The nesting sites are usually in relatively flat areas with low vegetation, and they are defended from other skuas and predators by both members of the pair. These birds usually lay two eggs, but in the case of one or both eggs failing they can attempt a second clutch. Chicks hatch usually ca. 30 days after the laying date, and they take approximately two months to fledge. (Furness 1987).

The Antarctic skua has two subspecies: the brown skua (*Catharacta antarctica lonnbergi*) and the Falkland skua (*Catharacta antarctica antarctica*), the latter one being almost endemic to the Falklands archipelago. This subspecies is facing a sharp decline on its population (Catry *et al.* 2011). Being a top predator on the islands (along with striated caracaras *Phalcoboenus australis*), the Falkland skua plays an important part on the ecosystem of the Falklands, exerting top down regulation on its preyed species. Also, being an endemic subspecies, it is important to study this bird to be able to predict and prevent impacts on its populations.

The Falkland Islands are an archipelago made of several hundred islands, including two main ones, West and East Falkland. These islands are predominantly mountainous and hilly. The archipelago is influenced by the Falkland current, coming from the Pacific Ocean into the Atlantic Ocean. New Island (51°43´S, 61°17´W) is one of the westernmost island of the Falklands. It is located approximately 500 kilometres to the northeast of South America and on the southern end of the Patagonian Shelf. The highest point of the island is approximately 226 meters above sea-level. The west side of the island is characterized by high cliffs and rough oceans, having important rookeries along the coast. The east side of the island is lower and characterized by sandy beaches and calm waters. The island is an important breeding area for many seabirds such as black-browed albatrosses (*Thalassarche melanophris*), rockhopper penguins (*Eudyptes chrysocome*), gentoo penguins (*Pygoscelis papua*), magellanic penguins (*Spheniscus magellanicus*), blue-eyed shags (*Phalacrocorax albiventer*), thin-billed prions (*Pachyptila belcheri),* white-chinned petrels (*Procellaria aequinoctialis*), dolphin gulls *(Larus scoresbii)* and Falkland skuas (*Catharacta antarctica antarctica*). Other important birds are known to reproduce on this island, such as striated and crested caracaras (*Phalcoboenus australis* and *Polyborus plancus*, respectively), red-back hawks (*Buteo polyosoma*), short-ear owls (*Asio flammeus),* upland and kelp geese (*Chloephaga picta* and *Chloephaga hybrida,* respectively*)* and black and pied oystercatchers *(Haematopus ater and Haematopus leucopodus*, respectively*).* In particular, this island holds the largest known breeding population of thin-billed prions (Catry *et al.* 2003), and the largest known colony of Falkland skuas (Catry *et al.* 2011).

There are almost no published studies conducted with this subspecies, so all information is important to get a better understanding of this bird's impact in the ecosystem and its possible repercussions in terms of future conservation efforts. In this study, there were two main objectives: 1) to test if it was possible to sex Falkland skuas using a discriminant function and 2) to describe and characterize the Falkland skua diet and its feeding ecology using different techniques and methods.

Chapter 2: Does morphological variation allows sex discrimination in Falkland skuas (*Catharacta antarctica antarctica*)?

Introduction

Many seabird species lack distinguishable external characteristics that enable a clear identification of their sex. A large variety of ecological studies (e.g. population structure and demography, life history research), require a practical and accurate method to determine the sex of the study animals. Behavioral observations (such as copulation, prey delivery among others) may enable sexing birds in pairs, but this method is time consuming and rather limiting since it is only possible with sexually active individuals and only during a particular moment of the breeding season (Coulson *et al.* 1983, Catry *et al*. 1999).

DNA-based techniques have proved efficiency in sexing seabirds (e.g. Griffiths *et al.* 1998), but these have their own shortcomings. This procedure can be difficult to execute in harsh weather conditions, and the analysis in itself can be time-consuming and it is usually expensive, which could be an obstacle in studies that involve a large number of samples.

Despite the absence of obvious morphological differences between sexes, many seabird species show some degree of size dimorphism, and therefore classification methods, such as discriminant analysis based on body measurements have been developed to determinate the genders of birds of unknown sex (Hammouda & Selmi 2013). With a discriminant function that combines the differences in several measurements it is expected that a higher proportion of the individuals is sexed, in relation to the use of a single measurement (Coulson *et al.* 2009). A discriminant analysis is a linear combination of the original given variables. It provides a set of weightings to distinguish the groups (in this case males and females), by maximizing the variability inter-groups relatively to the variability intra-groups. It can then be used on individuals of unknown sex to provide a probability (a score) of them belonging to each one of the groups, 'males' or 'females'. These individuals can then be assigned to the groups, the higher the probability the higher the level of certainty of the analysis. This type of approach has been used in many different species of birds including shags (Calvo & Bolton 1997), shearwaters (Granadeiro 1993, Genovart *et al.* 2003), petrels (Lorentsen & Røv 1994), penguins (Zavalaga & Paredes 1997), oystercatchers (van de Pol 2009), birds of prey (Borlotti 1984, Donohue & Dufty 2006, Muriel *et al.* 2010), terns (Fletcher & Hamer 2003), skuas (Ainley *et al.* 1985; Hamer & Furness 1991; Phillips & Furness 1997) and gulls (Fox *et al.* 1981, Coulson *et al.* 1983, Hanners & Patton 1985, Evans *et al.* 1995, Galarza *et al.* 2008, Hammouda & Selmi 2013). Despite its wide application, the method has its limitations, being dependent on the accuracy and precision of the body measurements (Hamer & Furness 1991), which are dependent on the experience of the fieldworker, and particularly on the degree of sexual size (or shape) dimorphism of the study species. If the studied species has high variability within each sex or small differences between them, the discriminant powers is decreased (Weidinger & Franeker 1998). It has been shown that by classifying both members of a pair will deliver a more efficient sex determination, due to assortative matting (Fox *et al.* 1981, Fletcher & Hamer 2003). Some species show a marked geographical in size, which can compromise the general applicability of this method. For this reason, each discriminant function should be applied only to the

species and population to which it refers to (Evans & Cavanagh 1995). Also, the usefulness of body parameters that might significantly change in time (e.g. weight) should be carefully analyzed.

The Falkland skua (*Catharacta antarctica antarctica*) is a poorly studied subspecies, part of the Stercorariidae family. The largest population of this seabird can be found on New Island (Falkland Islands), and it is facing a sharp decline in its numbers and breeding success (Catry *et al.* 2011). It is important to get basic information on this species to perform studies of their ecology and behavior, to better understand what is needed in terms of conservation in the present and in the future. All skua taxa display reversed sexual dimorphism (RSD) (Furness 1987), the females being larger than the males, a characteristic in common with other groups of birds like birds of prey and frigatebirds. In this study, morphometric parameters are used to sex birds from different territories of New Island by using a discriminant function.

Material and methods

Fieldwork

This study took place on New Island (51°43'S, 61°18'W), one of the westernmost islands of the Falklands archipelago. Biometrical data were collected throughout the years 2008 to 2015, during the breeding season, which on New Island starts in November with territory formation and egg laying and ends in February with the fledging of the chicks. Animals from different territories were captured by hand or with a hand-net which is possible as they defend their territory actively in flight or while landed. Five body measurements were taken: bill length (from the tip of the bill to the posterior ridge formed by the parietal-supraoccipital junction), gonys (bill height at the gonys), tarsus length, wing length (maximum flattened cord) and mass. These measurements were taken by different observers throughout the years. Wing length was measured with a rule to the nearest mm, mass was determined with a 2kg Pesola spring-balance to the nearest 10g and the other 3 parameters were obtained with a caliper, to the nearest 0.1mm.

Sexing skuas

A small blood sample was also obtained from the interdigital capillaries, and immediately stored in a small tube containing 98% ethanol for sex determination by molecular methods. Samples were then kept in room temperature until analysis. The extraction of the DNA was performed with the EZNA™ Tissue DNA Kit, using the protocol described by Fridolfsson and Ellegren (1999). The genes *CHD1Z/W* were subsequently amplified by means of polymerase chain reaction, using primers 2550F and 2718R. The PCR reaction, with a total volume of 15 µl, included 1 µl Taq Supreme (NZYTech), 0.27 mM of dNTP, 0.2 mM of each primer, 2 Mm of magnesium, 0.0067mg of BSA (Bovine Serum Albumin) and 1-3µl of DNA. The cycle used in the thermocycler included the following steps: 95ºC x 4 minutes + (95ºC x 30 seconds + 52ºC x 30 seconds + 72ºC x 40 seconds) x 35 + 72ºC x 7 minutes. Using an electrophoresis technique, the amplified fragments of DNA were separated in a 2% agarose gel, stained with Red Safe. The results were later revealed under UV light. Males were identified as having only one band in the gel and females having two bands in it.

Statistical analysis

Means and standard deviations were calculated for all measurements and for each sex. Normality of the data was tested by using Kolmogorov-Smirnov tests. Bill length and gonys were the only variables that showed significant deviation to a normal distribution. A t-test was performed on all the variables to test for differences between sexes.

A discriminant function was then used to sex the birds according to their external measurements, using the variables bill length, gonys, tarsus, wing length and mass. The proportions of correctly classified values were calculated by a jackknife cross-validation method, in which each individual is classified by a function derived from the total sample, except the bird to be classified. This procedure avoids overestimating the classification rates. Statistical analysis was performed using SPSS 22.0 (Statistical Package Social Sciences) and R 3.2.0 software (R Development Core Team).

Results

Mean values and ranges for each variable are shown in Table 1, for males and females from a total of 103 birds (51 males and 52 females) which were sexed by DNA analysis. Wing length, tarsus and mass were the variables that showed differences between sexes (t-test; t=-5.2, $p<0.001$, t=-4.4, $p<0.001$ and t=-6.7, $p<0.001$, with 108, 109 and 103 degrees of freedom, respectively). All variables showed considerable overlap between males and females, as demonstrated on Table 1.

Table 1. Morphometric data for male and female Falkland skuas used in the discriminant analysis.

	Males (n=51)		**Females (n=52)**	
	Mean	**Range**	**Mean**	**Range**
Wing length (mm)	389.1 ± 7.3	370-412	397.0 ± 8.1	374-414
Tarsus (mm)	68.7 ± 2.4	61.0-74.7	70.5 ± 2.0	66.6-74.5
Bill length (mm)	47.6 ± 2.3	43.7-51.9	48.2 ± 1.9	43.7-52.9
Gonys (mm)	18.5 ± 0.9	15.9-20.2	18.7 ± 0.7	17.0-20.7
Body mass (g)	1177.0 ± 103.2	1025-1575	1333.6 ± 135.9	1000-1675

Different discriminant analyses were performed on a sample of 103 individuals. Discriminant analysis using only one variable resulted in 70.9%, 65.8% and 79.0% birds correctly sexed, being the variables used wing length, tarsus and body mass, respectively. A discriminant analysis combining wing length and tarsus resulted in 73.4% success.

Discriminant analysis using wing length, tarsus, bill length, gonys and mass resulted in 79.6% of individuals correctly sexed (N=103) and 74.7% when mass is removed from the analysis. Using within-pair comparisons, i.e., if the criteria for sex determination is set to situation when the discriminant score of females is higher than that of males, the classification rate is increased to 89.2% (N=74 individuals) (Figure 1).

The probability of each individual being male or female based on its score is shown in Figure 2. When an individual has a score value is of approximately -1.25 there is 80% probability of it being a male, and 20% of it being a female. If the discriminant assigns a score of 1.25 to an individual, then the probability of it being a female is of 80%, and 20% a male. If the score value is 0, there is 50% probability of the individual being either female or male.

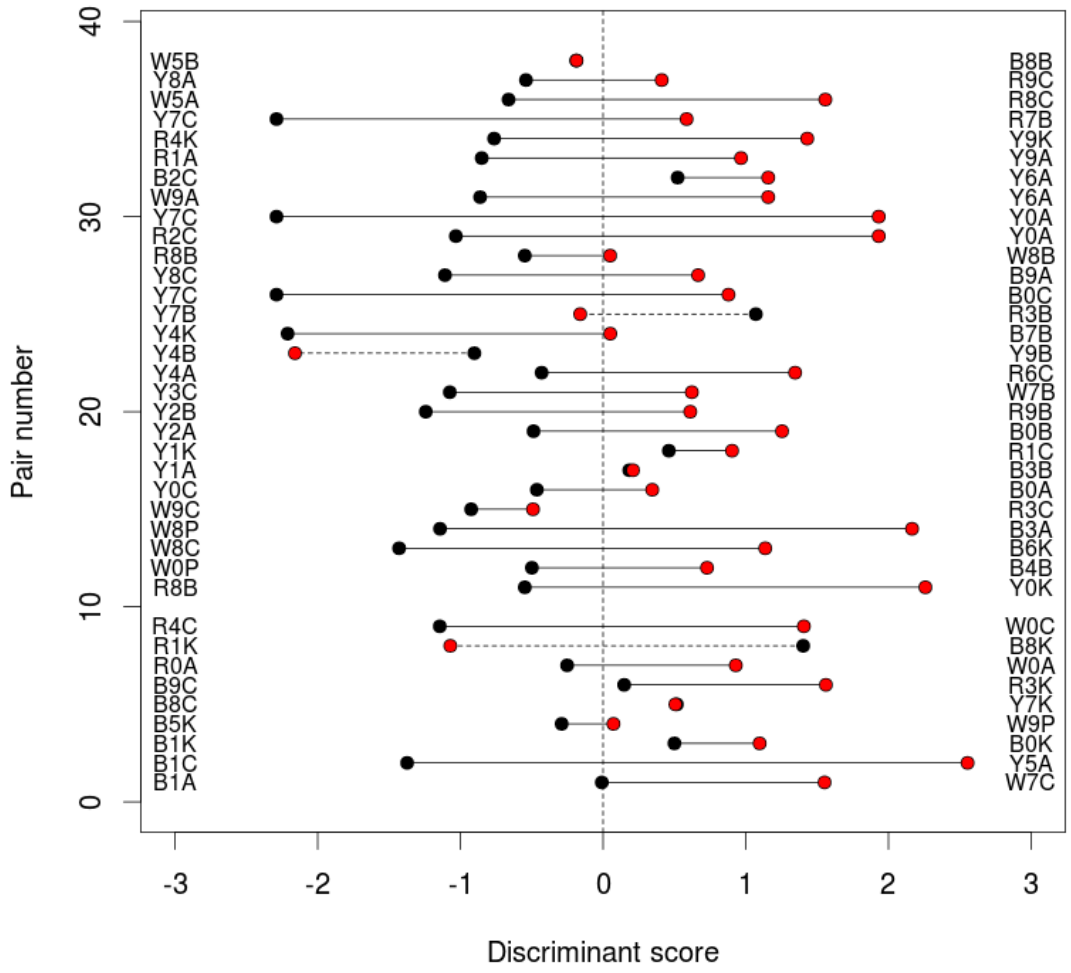

Figure 1. Discriminant scores of members of each pair of skuas sexed by DNA techniques (females and males are represented as red and black points, respectively). Letters indicate the ring number of females and males (right and left, respectively). Dashed lines connect pairs in which males have higher score (i.e. are larger) than females, i.e., with no reversed sexual dimorphism. Any score above 0 is classified as female and any score below 0 is classified as male.

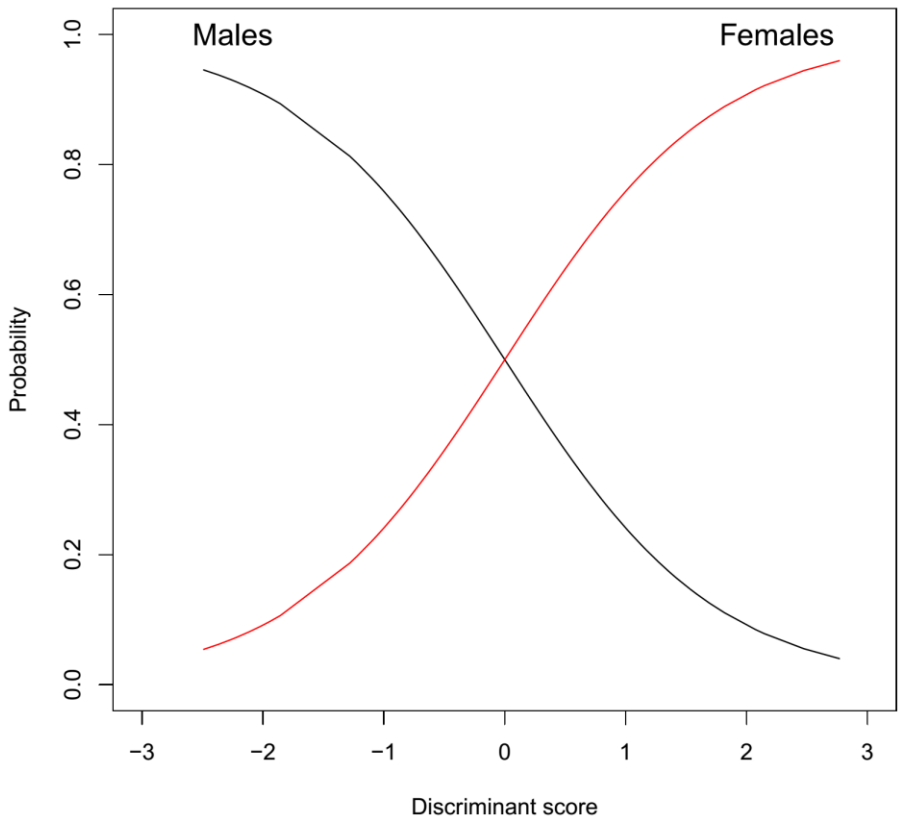

Figure 2. Probability of an individual being male or female according to the score given by the discriminant. When scores are of approximately -1.25, the probability of that individual being a male is 80%, and 20% of being a female. For score values of 0 the probability of being male or female is the same (50%).

Discussion

The classification rate achieved with the best discriminant function obtained in the present study does not provide a reliable, stand-alone method for sexing Falkland skuas but it is similar to other studies carried out in other seabird species (dovekies: Jakubas & Wojczulanis 2007, terns: Fletcher & Hamer 2003, Reynolds *et al.* 2008, penguins: Brummelhaus *et al.* 2015), and can be useful in cases in which DNA analysis cannot be performed. Even so, it is still advisable to use it along with direct observations of copulating behavior or courtship feeding. When a species has a high degree of overlap in morphometric parameters between sexes there is always the need of being cautious when deciding to use these external features on discriminant functions to sex the individuals (Nana *et al.* 2014). In cases in which scores are intermediate and therefore less likely to be correctly sexed, the sex can be inferred by molecular analysis. This would still be an improvement since it would not be necessary to be running expensive and time-costing analyses for big quantities of samples (Genovart *et al.* 2003).

Within-pair comparisons have showed to improve the discriminatory power of the variables used in this type of analysis in several published studies (Ainley *et al.* 1985, Weidinger & Franeker 1998, Jodice *et al.* 2000 and Fletcher & Hamer, 2003). This technique is more flexible and powerful than sample-level analysis for sexing birds from morphometric parameters (Fletcher & Hamer 2003). In the present study the use of this approach resulted in a clear improvement of the results. The obtained value of error dropped from 20.4% to 10.8% after using within-pair comparisons.

Some of the used biometric measures are common in previous studies. Parameters such as wing length and tarsus have been used to sex different types of birds, such as ospreys (Muriel *et al.* 2010), swans (Calabuig *et al.* 2011), shags (Calvo & Bolton 1997), greenbuls (Nana *et al.* 2014) and skuas (Hamer & Furness 1991 and Phillips & Furness 1997), usually along other parameters, depending on the species. However, parameters like wing length should be used with caution. A study on kittiwakes showed changes between lengths of primary feathers on the same individuals in different years, suggesting that these feathers do not grow to the same size every time the birds molt (Coulson 2009). This same study has shown that due to the normal wear of the tip of the primary the measurements can be reduced by several millimeters. It has also been shown that single parameters should not be used to sex birds (Freeman & Jackson 1990; Granadeiro 1993), although in species that show a high level of sexual dimorphism using single parameters can be the best approach. In general, measuring only one parameter can be useful, especially when working with a large number of individuals in a short period of time (Alarcos *et al.* 2007).

According to the results of this study, body mass improved the discriminant results, even though this variable is usually excluded in this type of studies. Body mass in birds during breeding season can vary greatly, sometimes even in the same day, since it is dependent on food availability, environmental conditions and patterns of activity of populations and individuals (Freeman & Jackson 1990). However, it can lead to great improvements when used in a discriminant function, and it has been used on some published studies throughout the years (Desrochers 1989, Fletcher & Hamer 2003, Donohue & Dufty 2006). Geographical variation between populations can also be an obstacle when applying the same discriminant function to the same species but in different areas, since environmental conditions can be different and therefore influence the body size and shape of the birds (Granadeiro 1993, Calvo & Bolton

1997, Coulson 2009). This problem does not seem to be relevant for the Falkland skua, since this subspecies is already restricted to a rather small area, usually affected by the same type of weather and environmental conditions. This fact can also explain why the use of mass in a discriminant function is adequate for the Falkland skua. Ideally the individuals used to create a discriminant function should be recaptured every few years, especially if body mass is one of the variables used, to check if the measurements of the same morphometric parameters would change.

The most reliable techniques to sex birds without clear sexual dimorphism involve molecular techniques, such as the DNA analysis used in this paper. Errors arising from the variability of measurements linked to age and to different fieldworkers collecting data are eliminated by using DNA amplification on sex chromosomes (Muriel *et al.* 2010). Discriminant functions are dependent on the precision and accuracy of the fieldworkers who take the measurements and their consistency throughout the years and populations of the same species (Hamer & Furness 1991). Although the sample of this study was obtained by multiple fieldworkers this could mean that the resulting discriminant function can be more easily applied in future work where the need to have different and multiple fieldworkers may arise, such as suggested on a similar study by Calvo and Bolton (1997).

Some discriminant functions for species within the Stercorariidae family have been developed in the past. Phillips and Furness (1997), working with Artic skuas (*Stercorarius parasiticus*), obtained good results when taking into consideration the mass by the time of incubation on their discriminant analysis (91% correctly sexed individuals), but these results changed greatly when the variable mass was not taken into account (75.8% of successfully sexed birds). Hamer and Furness (1991) were able to correctly sex between 73 and 77% of their sample of Great skuas using only wing length, and 71% using a discriminant function with tarsus and wing length. These values were similar to the results of this study for Falkland skuas when using the same variables. The power of discriminant functions in skuas seem to be lower than the ones in gulls, which usually register rates of success higher than 85% (Hanners & Patton 1985, Evans *et al.* 1995, Galarza *et al.* 2008, Hammouda & Selmi 2013), which may suggest that skuas have a lower degree of sexual dimorphism than their closest relatives, the Laridae. Since the most used and successful measurement in discriminant functions in gulls is the total length of head and bill, it could be interesting to use this variable in discriminant functions applied to skuas. In 1985, in a study with South Polar skuas, Anley, Spear and Wood (1985) also noticed that in every pair of their study population the females were larger than the males, being this way able to sex all the study birds only by body measurements and observations, without the need to use a discriminant function.

This is the first study using biometric data on the Falkland skuas. The obtained results can prove to be useful not only for future studies of this species (both ecological and conservational research) but also to bring some more insight on the discussed topic of the skua taxa.

Chapter 3 – Diet, trophic ecology and feeding behavior of the Falkland skua (*Catharacta antarctica antarctica*)

Introduction

Diet studies based on top predators are crucial to understand how the ecosystems work and evolve, and to predict changes in the future. These animals have an important stabilizing effect on the trophic system, preventing the loss of inferior competitors and keeping the numbers of prey species populations balanced (Paine 1996). Therefore, the decline of top predators can have serious impacts on ecosystems (Österblom *et al.* 2006, Heithaus *et al.* 2008). The Antarctic and sub-Antarctic ecosystems are especially fragile, having suffered from effects of climate change and human activities over the last decades (Carneiro *et al.* 2014). These changes have impacted top predators, leading to changes in abundance, distribution and phenology of different species across multiple trophic levels (Jenouvrier *et al.* 2005; Österblom *et al.* 2006, Ainley & Hyrenbach 2010).

Seabirds are known to adjust their foraging strategies according to different parameters like age, sex and breeding stage, as well as to both their energetic requirements and those of their offspring (Mougeot *et al.* 1998, McLeay *et al.* 2010, Phillips *et al.* 2011). This results in the exploitation of different and varied trophic niches and in changes in searching strategies during the breeding season (Shaffer *et al.* 2003, Carneiro *et al.* 2014). Recent studies also suggest that many species of seabirds may show individual feeding specializations, these not being necessarily sex-specific (Masello *et al.* 2013, Patrick *et al.* 2014). This plasticity in terms of foraging behavior within and between individuals is important, particularly if the abundance and distribution of different prey is variable (Hamer *et al.* 2007). In polar and cold-temperate regions, the feeding conditions for birds may be highly variable, and sometimes lead to complete reproductive failure (Hahn & Peter 2003). In those areas, generalist predators will benefit from the ability to exploit different trophic resources, whereas specialists will not. Individuals or groups of individuals may adopt strategies like territoriality at specific feeding areas, to ensure exclusive access to food (Maher & Lott 2000). The occupation and defense of feeding territories should improve the breeding success of these animals (Hahn & Peter 2003), as long as the energy dispended is compensated by the food they have available and they can still defend their breeding territory.

Different techniques can be used to assess seabird diets (Duffy & Jackson 1986). The method that provides the most accurate information on food ingested is direct observation of feeding behavior, although this is time consuming and susceptible to biases towards the most conspicuous prey (Votier *et al.* 2003, Ramos *et al.* 2009). As an alternative, diets can be sampled after food capture (prey remains) or ingestion (regurgitated pellets of indigestible materials) (Votier *et al.* 2003). Both prey remains and regurgitated pellets provide large sample sizes, but prey can be difficult to identify on regurgitates (Ramos *et al.* 2009). These methods can also lead to an overestimation in the final reconstructed diet, since different prey types can have different resistances to digestion (González-Sólis *et al.* 1997, Votier *et al.* 2003). Extensive monitoring over time is recommended to obtain consistent information on feeding habits of a population since each sample of these techniques represents only a specific feeding event (Votier *et al.* 2001).

According to Bearhop *et al.* (2001), the use of conventional techniques combined with stable isotopes should contribute to a more complete and conclusive diet description. The use of stable isotope

analysis in trophic ecology studies has been increasing throughout the years (Post 2002). This method avoids prey digestibility biases since it only takes into account assimilated food, but it does not provide taxonomic detail in terms of consumed prey (Ramos *et al.* 2009). It also takes into consideration prey assimilated over timescales of days to months, depending on the tissue used for the analysis (Cherel & Hobson 2007, Inger & Bearhop 2008). Stable isotopes of nitrogen (15N/14N, δ15N) provide information on the food web interactions and the trophic positions of species since predators are typically enriched in 15N (Post 2002, Vanderklift & Ponsard 2003). The ratio of 15N increases in a stepwise manner by 3–5‰ at each trophic level (Bearhop *et al.* 2000, Phillips *et al.* 2009). Stable isotopes of carbon (13C/12C, δ13C) also increase with trophic level but to a lesser extent (0.5–1‰). They are mainly used to determine sources of primary production, making it possible to retrieve spatial information including reliance on inshore vs offshore food items or benthic vs pelagic diet (Bearhop *et al.* 2000, Phillips *et al.* 2011). By combining the isotope ratios of consumer tissues with the isotopic values of prey items it is possible to have a better understanding about the trophic web where that consumer is inserted in.

Skuas are seabirds of the family Stercorariidae, closely related to gulls (Laridae). It is common for these animals to have a different diet during the breeding season compared to the diet during the rest of the year, relying mostly on terrestrial resources during the former (Furness 1987). Skuas are opportunistic predators and scavengers in both marine and terrestrial environments, occupying a crucial position as one of the top predators in the Antarctica and the sub-Antarctic region (Anderson *et al.* 2009). Being opportunistic, these animals show a high degree of flexibility in foraging behaviour which enables them to exploit a wide range of food resources (Moncorps *et al.* 1998, Anderson *et al.* 2009). Even so, some individuals can specialize on catching small petrels at night (Mougeot *et al.* 1998). Past studies show that the diets of these birds can vary in space and time and both within and among colonies, according to the availability of prey (Moncorps *et al.* 1998 e Phillips *et al.* 2004). Southern hemisphere skuas depend on fewer prey types than the northern hemisphere species, feeding mostly on seal carcasses and placentae, and on eggs, chicks and adults of seabirds nesting in the surrounding area (Reinhardt *et al.* 2000, Carneiro *et al.* 2014). South polar skuas (*Catharacta maccormicki*) and brown skuas (*Catharacta antarctica lonnbergi*) diets have been characterised at different areas and years (Mund & Miller 1995, Moncorps *et al.* 1998, Mougeot *et al.* 1998, Baker & Barbraud 2001, Phillips *et al.* 2004, Malzof & Quintana 2008, Anderson *et al.* 2009, Grilli & Montalti 2012), but even for these species little is known about their foraging behaviour and movements during breeding season. Studies of foraging movements using GPS loggers on brown skuas have only now started being published (Carneiro *et al.* 2014, Carneiro *et al.* 2015).

Some species of skuas are known to hold and defend feeding territories throughout the breeding season. In the Arctic, skuas of the *Stercorarius* genus occupy and defend vast territories (Maher 1974). In the Antarctica (and on sub-Antarctic islands) some breeding pairs of skuas of the *Catharacta* genus can defend territories in seabird colonies of penguins or petrels, while others forage on a larger area that they do not defend (Mougeot *et al.* 1998, Hans and Peter 2003, Carneiro *et al.* 2014). Several studies have shown that Brown skuas holding and defending feeding territories have

their chicks earlier in the breeding season and these show higher survivorship and earlier fledging than those of nonterritorial pairs (Hahn and Peter 2003, Hahn and Bauer 2008, Carneiro *et al.* 2015).

The Falkland skua (*Catharacta antarctica antarctica*) is a species nearly endemic to the Falklands archipelago. Its largest breeding population is found on New Island and it has been suffering a decline in numbers (Catry *et al.* 2011). There is only a small number of published papers about this subspecies, and none describing its diet and feeding behavior. Since reproduction is known to be affected by changes in food abundance in both the great skua (*Catharacta skua*) and the Arctic skua (*Stercorarius parasiticus*) (Hamer *et al.* 1991, Phillips *et al.* 1996), a characterisation of diet composition of the Falkland skua appears to be an important research object, with possible implications for future studies.

One of the main preys of Falkland skuas is the thin-billed prion (*Pachyptila belcheri*), a burrowing petrel that has its largest breeding population on New Island, Falkland Islands (Catry *et al.* 2003). Silva *et al.* (2011) suggested that the skuas nesting close to the main concentrations of prion burrows relied mainly on this species as their food source, but this was never confirmed. Other commonly preyed seabirds are rockhopper penguins (*Eudyptes chrysocome*), gentoo penguins (*Pygoscelis papua*), blue-eyed shags (*Phalacrocorax atriceps*) and black-browed albatrosses (*Thalassarche melanophris*).

The main objective of this study was to describe and characterize the diet of the Falkland skua on New Island, Falkland Islands. To this end, different techniques were used: pellet analysis, prey remains, stable isotope analysis, geo-tracking with GPS loggers and direct observations of territorial behaviour. Other specific objectives were to assess the variability of diets amongst pairs of the same population of skuas, to determine if the birds were obtaining their food exclusively on the island or in the ocean, to determine how long their foraging trips last and investigate how defending a feeding territory impacts breeding performance. Hatching date and the number of chicks alive by the end of the breeding season were also taken into consideration in this study, to assess if this is somehow related to their feeding behaviour and if the Falkland skua is still facing a sharp decline on its main known breeding population.

Material and Methods

Fieldwork

This study took place on New Island (51°43S, 61°18W), one of the westernmost islands of the Falklands archipelago, during the austral summer of 2014/2015. This island has the largest known breeding population of Falkland skuas (Catry et al. 2011). For this study only the areas in the center of the island were considered, a total of 49 territories, which corresponds to 47 breeding pairs (2 territories were being hold by skuas that did not attempt to breed during this breeding season). New Island is an important breeding ground for many seabirds, having an estimated population of 2 million pairs of thin-billed prions (Catry *et al.* 2003), and significant colonies of three species of penguins (magellanic, gentoo , and rockhopper), as well as blue-eyed shags and black-browed albatrosses. One of the most important breeding areas on the island is the settlement rookery, an area where rockhopper penguins, blue-eyed shags and black-browed albatrosses congregate to breed, being an important feeding ground for kuas.

Pellets

Many seabirds are known to regurgitate indigestible prey remains in pellets, which can be easily collected and examined to identify their contents (Barrett *et al.* 2007). Different studies with skuas used pellet analysis (Mund & Miller 1995, Phillips *et al.* 1997, Moncorps *et al.*1998, Votier *et al.* 2003, Malzof & Quintana 2008, Graña-Grilli & Montalti 2011). This technique does not reflect the real proportions of different prey in the diet of skuas, but it is nevertheless useful for comparison purposes between the importance of different prey for these animals and between different territories of skua (or even to compare diets in time).

From the beginning of January to the middle of February 49 nesting sites of Falkland skuas were visited weekly (in a total of 6 weeks), and both prey remains and regurgitated pellets were retrieved, identified and removed (to avoid recounting on next visits). All items were counted in the first visit to the territories. Skua pellets usually consist of one prey only, but in the rare events of more than one prey being present, the occurrences of each prey was noted. The pellets were sorted according to their contents: prions (*Pachyptila belcheri*), other birds (*Eudyptes chrysocome, Phalacrocorax atriceps, Thalassarche melanophris*), unidentified eggs, unidentified fish, lobster krill (*Munida gregaria*), goose barnacles (*Lepas* sp.), and others including echinoderms and plants. The prey remains usually found consisted of thin-billed prion wings (only left wings were counted and recorded as one individual - both adult and chick ones), empty egg shells (identified as being rockhopper penguin, blue-eyed shag, black-browed albatross or thin-billed prion eggs), skulls or wings of penguins, shags, albatrosses or geese, fish bones, lobster krill and seashells (from goose barnacles). The possibility exists that some prey are caught and consumed outside the territory, not leaving remains to be found in the territories.

Isotope analysis

This technique is based on the fact that stable isotopes ratios of carbon ($\delta_{13}C$) and nitrogen ($\delta_{15}N$) in tissues pass from prey to predator in a predictable way (Barrett *et al.* 2007). The ratios of stable isotopes are dependent on the tissues used for analysis. Plasma gives information of the items consumed in a

short period of time before its collection, being the best choice to evaluate the diet of animals in that particular moment. The carbon isotope ratios can be useful to identify the locations where seabirds feed, in terms of being close to shore or far in the ocean (Barrett *et al.* 2007).

Blood samples were taken of 24 Falkland skuas during late incubation period, one for sexing purposes and another for isotope analysis. The latter was dried and stored till analysis. Before the analysis, the blood samples were ground into powder. Sub-samples were created from weighting approximately 1.0 mg of the powered blood in a thin capsule on an analytical balance. The 13C and 15N ratios in the samples were determined by using a continuous flow isotope mass spectrometry (CF-IRMS) (Preston and Owens, 1983), on a Sercon Hydra 20-22 (Sercon, UK) stable isotope ratio mass spectrometer, coupled to a EuroEA (EuroVector, Italy) elemental analyzer for online sample preparation by Dumas-combustion. Protein Standard OAS, Sorghum Flour Standard OAS (Elemental Microanalysis, UK) and IAEA-N1 (IAEA, Vienna, Austria) were the standards used for nitrogen and carbon isotope ratio. Precision of the isotope ratio analysis was ≤ 0.2‰, calculated by using values from 6 to 9 replicates of laboratory standard material intermixed among samples in every batch analysis. Stable isotope ratio analyses were performed at the Stable Isotopes and Instrumental Analysis Facility (SIIAF) of the Centre for Ecology, Evolution and Environmental Changes (Ce3C), University of Lisbon – Portugal.

The blood sample retrieved for molecular sexing of the birds was stored in a small tube and preserved in ethanol, and the samples were kept in room temperature until analysis. The extraction of the DNA was performed with the EZNA™ Tissue DNA Kit, using the protocol described by Fridolfsson and Ellegren (1999). The genes *CHD1Z/W* were subsequently amplified by means of polymerase chain reaction, using primers 2550F and 2718R. The PCR reaction, with a total volume of 15 µl, included 1 µl Taq Supreme (NZYTech), 0.27 mM of dNTP, 0.2 mM of each primer, 2 Mm of magnesium, 0.0067mg of BSA (Bovine Serum Albumin) and 1-3µl of DNA. The cycle used in the thermocycler included the following steps: 95ºC x 4 minutes + (95ºC x 30 seconds + 52ºC x 30 seconds + 72ºC x 40 seconds) x 35 + 72ºC x 7 minutes. Using an electrophoresis technique, the amplified fragments of DNA were separated in a 2% agarose gel, stained with Red Safe. The results were later revealed under UV light. Males were identified as having only one band in the gel and females having two bands in it.

Tracking

Skuas nesting in different areas of territories around the center of the island were chosen based on their stage in the breeding season. A total of 23 GPS devices were deployed in skuas with eggs near hatching (late incubation period), to try to minimize the probability of the animal not returning to its nest site. The animals were captured by hand which is possible due to their typical behavior during breeding season of staying near the nests while defending their territory. The deployments were performed from 21 to 30 of December of 2014, and the devices were retrieved 5 to 6 days later. The GPS loggers weighted 13.5g including waterproof packing and they were attached to the dorsal feathers with TESA® tape. The total weight of the instruments were of approximately 15g, which is equivalent to 1.2% of the mean body mass for this species, which is around 1257g(±139.80) (personal data), being below the threshold (3%) recommended for deployments on this type of marine birds (Phillips *et al.* 2003). The

GPS loggers collected points every 2 minutes and it was possible to retrieve information about the total of kilometers travelled by the individuals, maximum range of their trips and the duration of each foraging trip.

For the purpose of this work, trips were defined as being movements lasting longer than 30 minutes and/or straying away from the nesting site more than 500 meters. Three bathing sites used by skuas of the study area were identified, one in the center and one in front of the settlement rookery (Figure 1). The third bathing area is located in the south of the island (Figure 2). The movements performed by skuas directly to these areas and within a range of 500 meters within them were assumed to be trips for bathing, and not foraging purposes. Night time was defined as the period between civil nights, when the sun angle is < -6º below horizon, which on New Island during this study corresponded to approximately 22:15 to 04:00 hours. Night trips were defined as the night movements that skuas performed from the moment they distance themselves from their nesting site more than 1 kilometer. These were only counted when skuas left their nests already during night time and returned still within this period, to avoid counting returning flights from longer foraging trips. A foraging trip to the ocean was considered every time a skua would stray away more than 5 kilometers from its nesting site. The farthest point from the island that each skua reached during the period of 5 days of tracking was considered to be the longest foraging trip performed by that individual.

Maps were produced with the help of R 3.2.0 software (R Development Core Team).

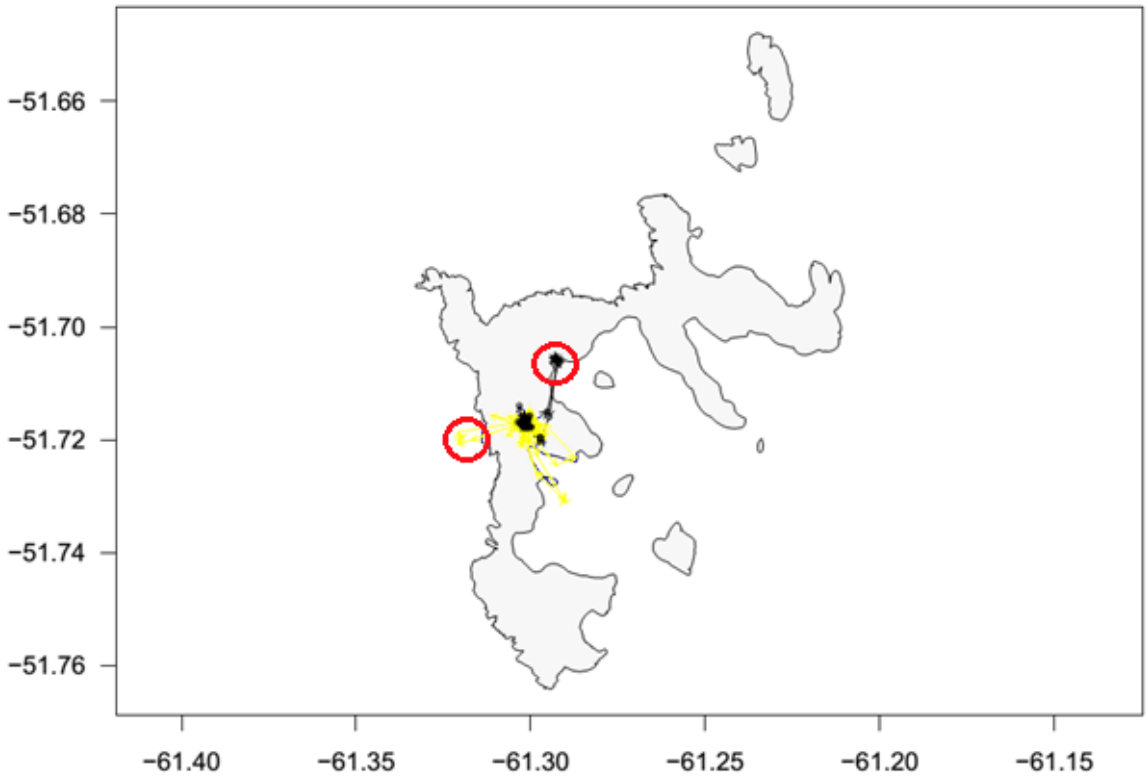

Figure 1. Map of New Island showing movements of Falkland skua (yellow and black). The bathing areas of the center of the island are marked as red, one in the east side of New Island and the other in front of the settlement rookery, on the west side of the island.

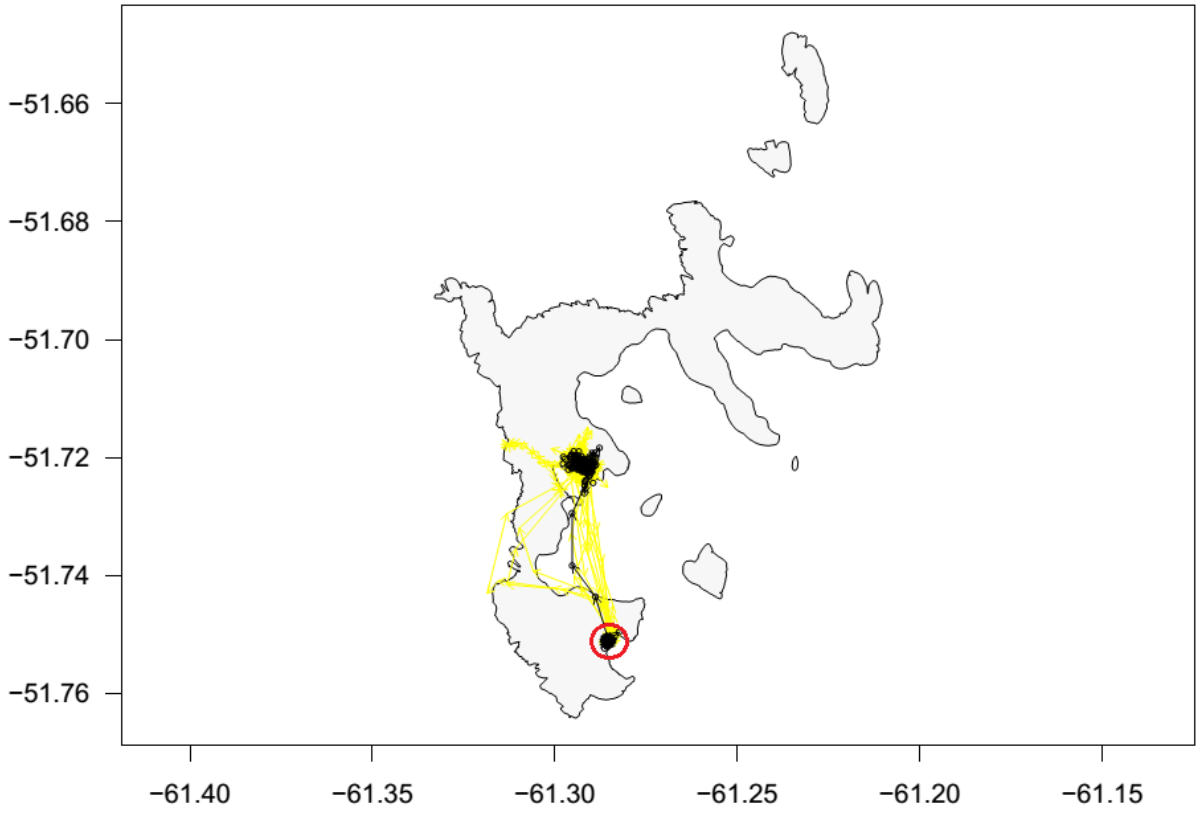

Figure 2. Map of New Island showing movements of Falkland skua (yellow and black). The bathing area of the south of the island is marked as red.

Territoriality on feeding grounds

Direct observations were made at the settlement rookery, the main area on the west of New Island where black-browed albatrosses, rockhopper penguins and blue-eyed shags congregate to breed. In the beginning of the breeding season (November/December), some observations were made to register the areas where skuas were more likely to be sighted feeding. Three areas within the rookery were clearly preferred by these animals, being those the largest areas where all three aforementioned species were breeding. Skuas showed none or low interest in smaller colonies, especially the ones amidst the tussac vegetation that exists in abundance throughout the rookery. During January and February direct observations were made in the three most preyed areas by Falkland skuas, in a total of 5 hours per week and per area. The birds that were seen catching food items in a specific place and eating them there, while defending that particular area from competitors (through displays or quick chases), were identified and considered to be holding a feeding territory in that location, as in previous studies (Young 1994, Hahn & Peter 2003). With this information it was possible to identify all territorial pairs of skuas defending a feeding territory on the different areas. Individuals performing foraging flights in these areas were also sighted but due to their speed of flight their rings could not be read. Territorial skuas displayed agonistic behaviors towards these animals, and these were seen capturing food in the

colonies while flying, being chased away by the skuas defending those same areas as their feeding territories.

Breeding parameters

For the purposes of this study breeding success was defined as the number of chicks alive at the end of February, time in which the researcher left the island. At this point of the breeding season most chicks were already fledged. Hatching date refers to the hatching date of the first chick of each skua breeding pair.

Statistical analysis

Frequency of occurrence of different prey items was calculated using the formula $FO = \frac{n_x}{N}$, in which n_x represents the number of pellets with a specific type of prey and N the total number of pellets found in that territory during the 6 weeks of sampling. A principal component analysis (PCA) was performed mainly to summarize the dietary information, using frequencies of occurrence obtained by pellet analysis.

To test differences between males and females and between different nesting areas in isotopic signatures a two-way analysis of variance (ANOVA) was used. Independent t-tests were performed to test differences between territorial skua pairs and non-territorial skua pairs for three different variables: hatching date, breeding success and distance from nesting site to rookery. Spearman's rank order correlation tests were used to investigate possible significant correlations between different variables, such as stable isotope ratios, frequency of occurrence of main prey items, breeding success, hatching date, distance from nesting site to rookery, and longest foraging trip. Statistical analyses were performed using SPSS 22.0 (Statistical Package Social Sciences) and R 3.2.0 software (R Development Core Team).

Results

Diet of Falkland skuas

A total of 1595 pellets and 3415 prey remains were analysed (Tables 1 and 2). The sampled territories classified into “Rookery” (n=21) and “Beef Point” (n=28). “Rookery” territories are the ones closer to the settlement rookery (distances from the nest to a central point of the rookery ranging from 42 to 744 meters), while “Beef Point” comprises 21 skua territories on Beef Point (area on the east of the island) and 7 more territories next to a prion patch south of the settlement area (distances from the nests to a central point of the rookery ranging from 1620 to 2183 meters).

Table 1. Frequency of occurrence of each prey species found in skua pellets.

	Rookery		**Beef Point**		**Total**	
Number of analysed pellets	(n=502)		(n=1093)		(n=1595)	
Number of skua pairs sampled	(n=21)		(n=28)		(n=49)	
Prey	n	%	n	%	n	%
Birds						
Thin-billed prion *Pachyptyla belcheri*	199	39.6	956	87.4	1155	72.4
Adults	187	37.2	903	82.6	1090	68.3
Chicks	12	2.4	53	4.8	65	4.0
Black-browed albatross *Thalassarche melanophris*						
Chicks	1	0.2	0	0	1	0.1
Falkland skua *Catharacta antarctica antarctica*						
Chicks	1	0.2	0	0	1	0.1
Unidentified birds						
Chicks	3	0.6	0	0	3	0.2
Eggs	76	15.1	20	1.8	96	6.0
Fish						
Unidentified fish	4	0.8	1	0.1	5	0.3
Crustaceans						
Goose barnacles *Lepas* sp.	14	2.8	74	6.8	88	5.5
Lobster krill *Munida gregaria*	281	56.0	135	12.3	416	26.1
Echinoderm						
Unidentified echinoderm	0	0	1	0.2	1	0.1
Plants						
Algaes	0	0	1	0.1	1	0.1
Berries	0	0	12	1.1	12	0.7
Unidentified	2	0.4	14	1.3	16	1.0

Throughout all the nesting areas sampled, thin-billed prions (*Pachyptyla belcheri*) showed to be the most important item on the diet of skuas, representing 72.4% of the total pellets found. Eggs

were difficult to identify to species with certainty while being in pellets, so they were taken into consideration as a general category. Results from prey remains analysis were broadly similar to the ones from pellet analysis. Eggs showed higher presence on the diet of Falkland skuas with this methodology (15.3% in total). Thin-billed prions had higher occurrence in “Beef Point” territories while the main prey in “Rookery” territories were lobster krill and eggs from other seabirds.

Table 2. Prey remains identified on the 49 studied territories.

	Rookery		**Beef Point**		**Total**	
Number of prey remains counted	(n=727)		(n=2688)		(n=3415)	
Number of skua pairs sampled	(n=21)		(n=28)		(n=49)	
Prey species	**n**	**%**	**n**	**%**	**n**	**%**
Mammals						
Rabbit (order Lagomorpha)	0	0	1	<0.1	1	<0.1
Birds						
Black-browed albatross *Thalassarche melanophris*						
Chicks	5	0.7	0	0	5	0.1
Thin-billed prion *Pachyptyla belcheri*						
Adults	186	25.6	2486	92.5	2672	78.2
Chicks	2	0.3	9	0.3	11	0.3
Eggs	0	0	5	0.2	5	0.1
Rockhopper penguin *Eudyptes chrysocome*						
Chicks	6	0.8	0	0	6	0.2
Eggs	470	64.6	0	0	470	13.8
Blue-eyed shag *Phalacrocorax atriceps*						
Chicks	4	0.6	1	<0.1	5	0.1
Eggs	48	6.6	0	0	48	1.4
Magellanic penguin *Spheniscus magellanicus*						
Adults	0	0	1	<0.1	1	<0.1
Chicks	0	0	1	<0.1	1	<0.1
Upland goose *Chloephaga picta*						
Adults	1	0.1	1	<0.1	2	<0.1
Crustaceans						
Goose barnacles *Lepas* sp.	0	0	174	6.5	174	5.1
Lobster krill *Munida gregaria*	3	0.4	3	0.1	6	0.2
Fish						
Unidentified fish	2	0.3	6	0.2	8	0.2

Thin-billed prions were the main prey of Falkland skuas. On average, 54.5 (±78.3) left wings of thin-billed prions were found on each skua territory, during the six weeks of sampling (2672 left wings from adults in total / 49 territories sampled; min=0, max=312).

A PCA analysis of the frequency of occurrence of pellets found in our study territories was carried out to summarise the dietary data (Figure 3). This analysis revealed that most of the variation in our dataset was associated with the consumption of prions and their chicks, which was negatively related with the frequency of lobster krill (*Munida gregaria*). On the other hand, the second principal component was mostly associated with the presence of shells of the pelagic cirriped *Lepas* sp..

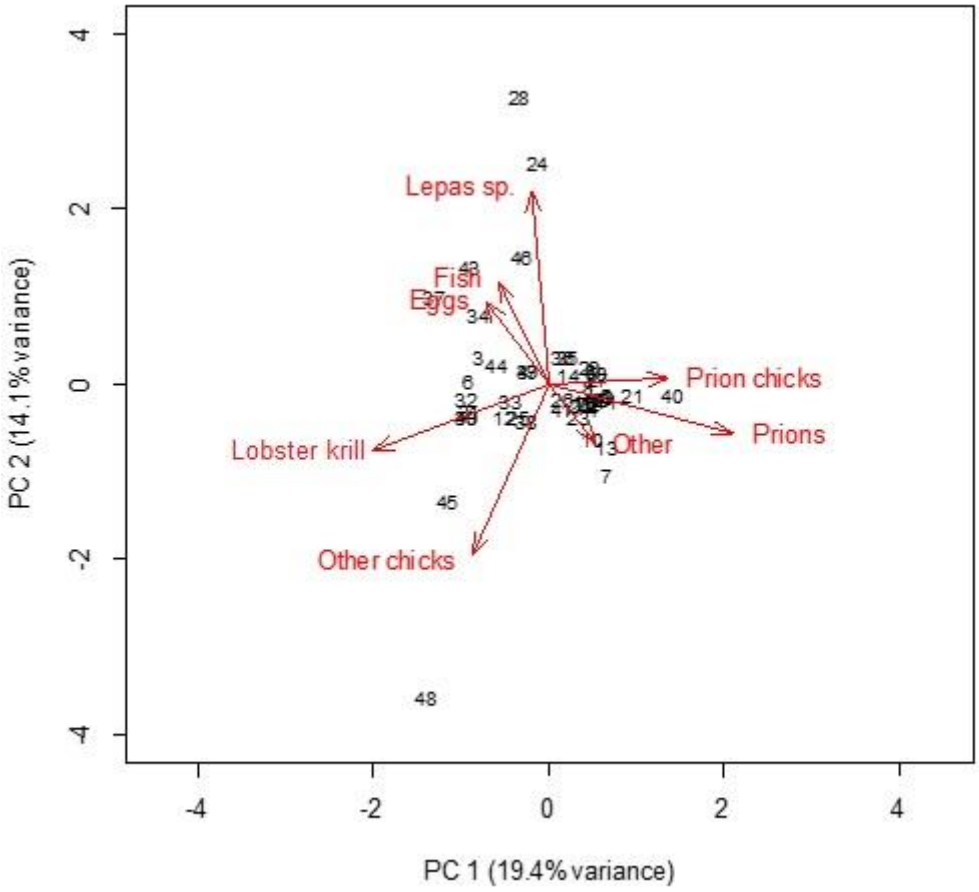

Figure 3. PCA analysis summarizing the frequency of occurrence of pellets found in territories of Falkland skuas (n=49).

Stable isotopes in blood of Falkland skuas

We tested differences in the isotopic signatures between males and females and between different nesting areas using a two-way analysis of variance. There were no significant differences in $\delta_{13}C$ and $\delta_{15}N$ values between sexes (respectively -18.11(±0.57) and 13.47(±1.57) (n=24) $F_{1, 21} = 0.01$ and $F_{1, 21} = 0.64$, both NS), but the differences between "Rookery" to "Beef Point" were significant (respectively $F_{1, 21} = 10.5$ and $F_{1, 21} = 32.7$, both $p<0.005$, Figure 4). Moreover, the $\delta_{13}C$ and $\delta_{15}N$ values of the sampled birds were significantly negatively correlated with the distance between nesting sites of skuas

and the settlement rookery (Spearman's rank correlation: r^s=-0.599, p=0.004 $\delta_{13}C$ and r^s=-0.687, p=0.001 for $\delta_{15}N$ (n=24))

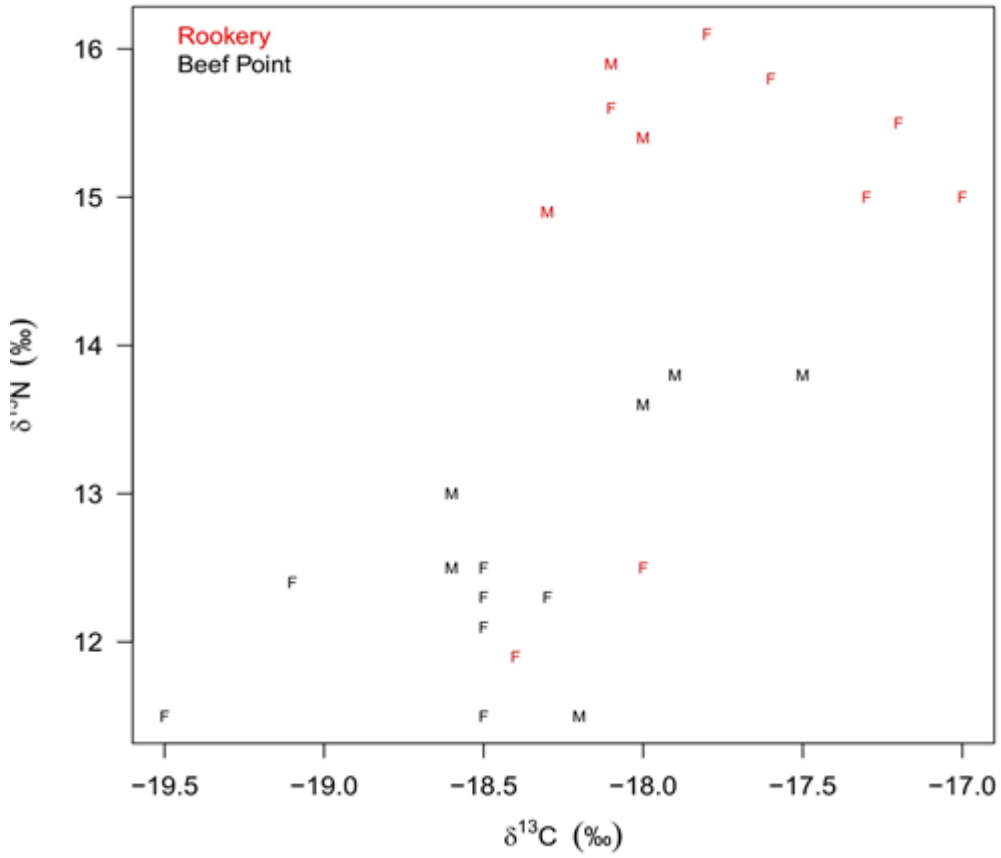

Figure 4. Stable isotope ratios of 24 Falkland skuas on late incubation period. Female skuas are represented by F and male skuas are represented by M. Individuals marked as red had nesting sites in "Rookery" territories, while individuals marked as black had nesting sites in "Beef Point" territories.

Tracking

We tracked 23 individuals for an average of 5 days (min=1 days, max=6 days, mean=4.85±1.27). Most animals made several small movements on the island and foraging trips to the ocean or to other islands were rare. Out of the total sampled birds, 8 skuas performed foraging trips to the ocean (Figure 6). The frequency of these trips differed between animals, being on average 0.83 (±1.49) trips per bird during the period of study (n=23). On average, these foraging trips lasted 3.03 (±2.34) hours, the shortest being one hour long and the longest nine hours. The number of foraging trips to the ocean per skua did not show a clear correlation with the distance between the nests and the settlement rookery (Spearman's rank correlation; r^s=0.406, p=0.055, n=23).

As shown in Figures 5 and 6, Falkland skuas show mostly diurnal activity (marked as yellow) but a few movements were carried out during nocturnal activity (night was defined as the period between civil twilights, i.e. when the sun angle is < -6º below horizon, corresponding to 22:15 to 04:00) (Figure 7). During the period of tracking, these animals did on average 0.91 (±1.65) trips during night

time, the number of trips ranging from 0 to 7 per bird. The frequency of night trips did not show any significant correlation with the frequency of trips made to the main concentrations of prion burrows of New Island (Spearman's rank order correlation; r^s=0.270, p=0.213, n=23), neither when correlated with the frequency of occurrence of pellets with prions (Spearman's rank order correlation; r^s=0.017, p=0.939).

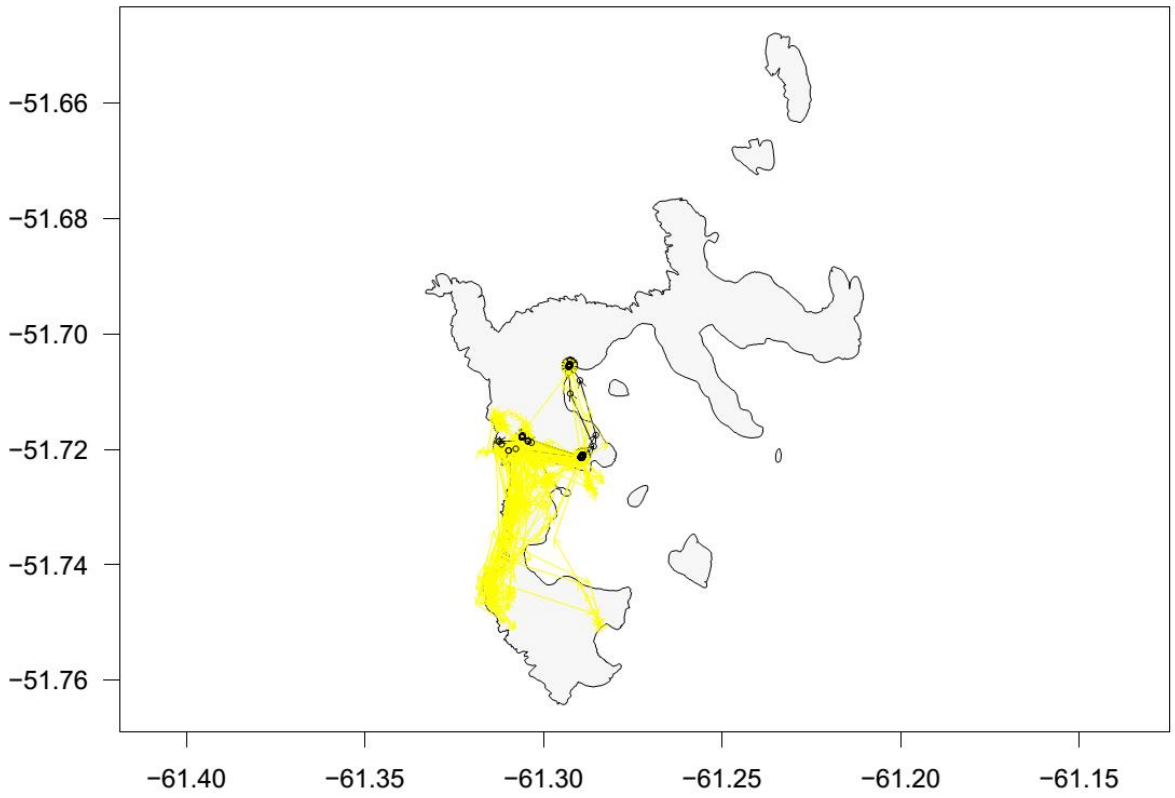

Figure 5. Example of movements of Falkland skua, presumably foraging on the island. The yellow lines represent movements performed by the skuas during daytime (on New Island from 04:00 to 22:15), and the black lines to the ones performed during night time.

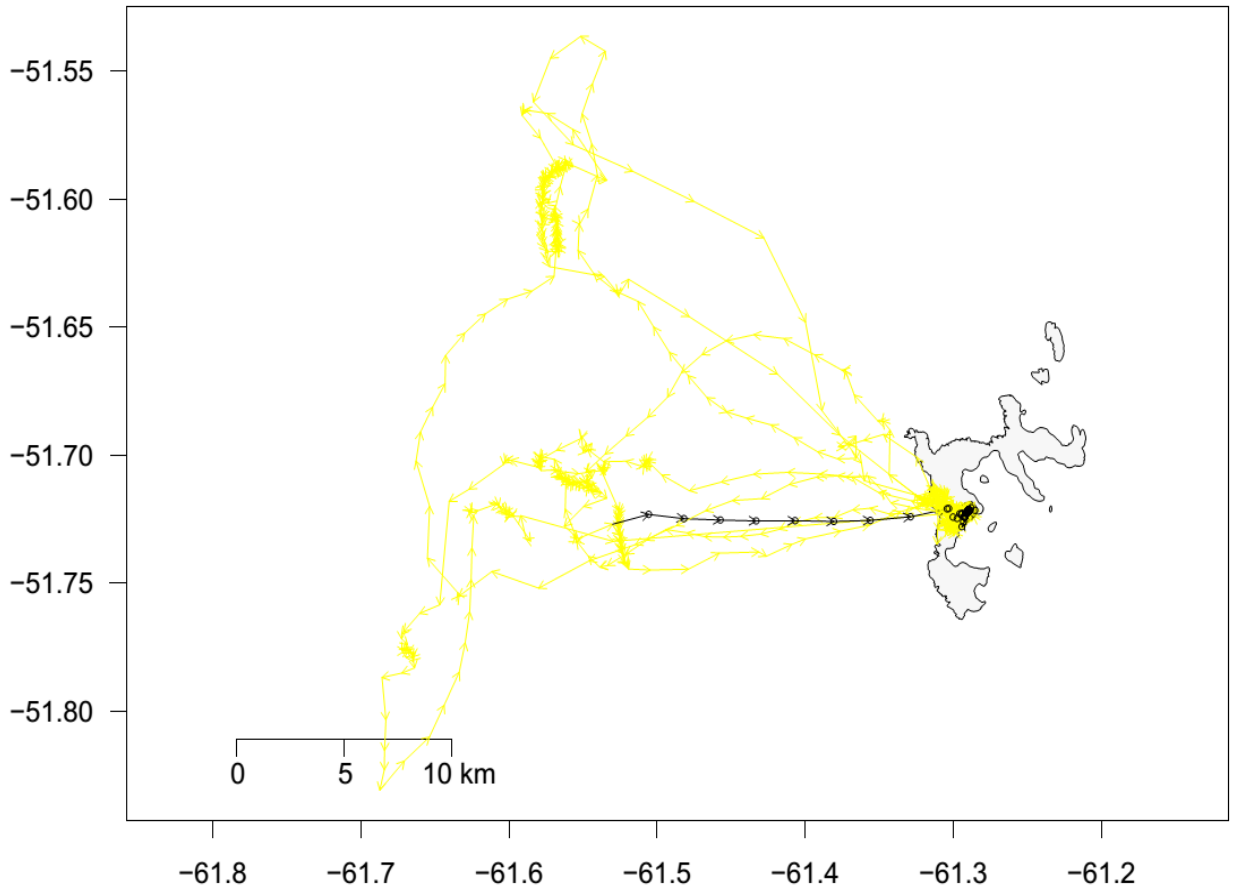

Figure 6. Example of foraging trips of Falkland skua towards the ocean (yellow lines represent daytime and black lines represent night time).

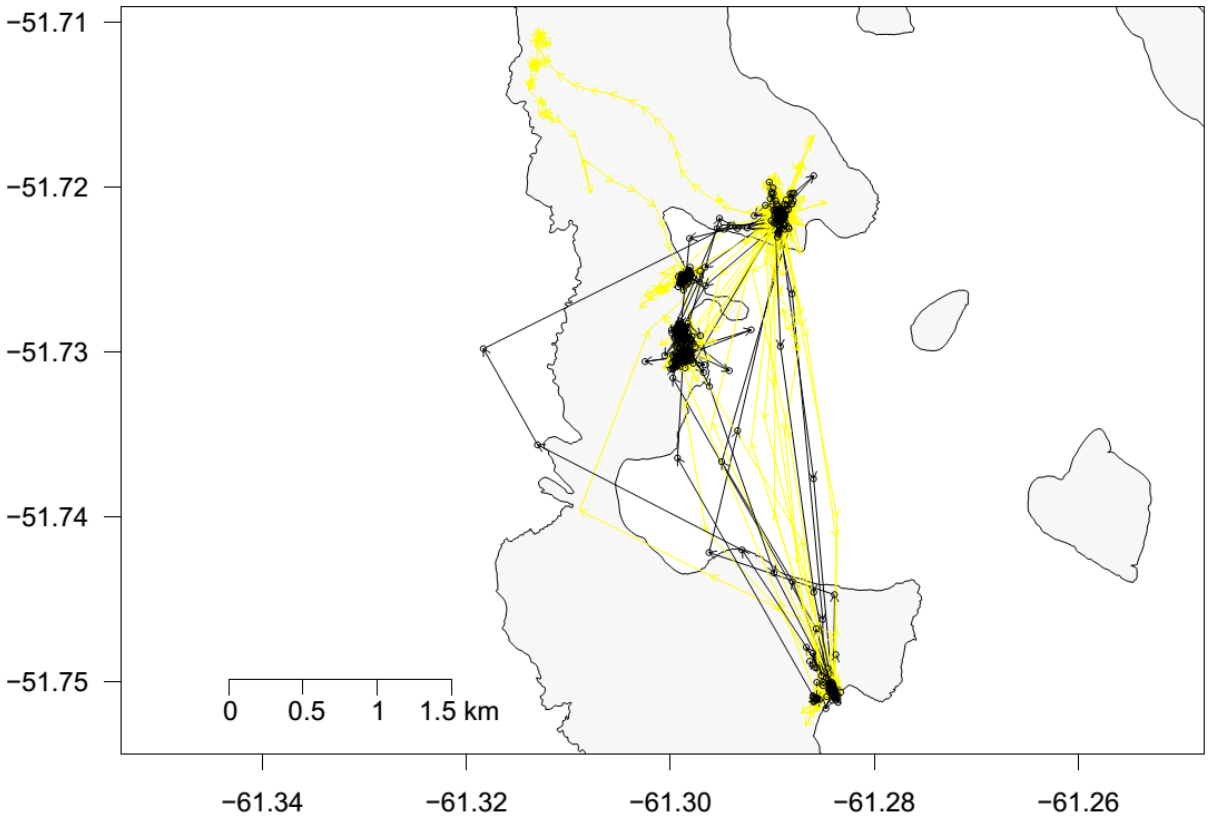

Figure 7. Foraging trips of Falkland skua, showing nocturnal movements to a bathing area in the south and to areas of high density prion nesting areas (black).

Relationship between diet, isotopes and foraging behaviour

The correlation between the frequency of occurrence of the most common prey in skua diet with 6 other variables was tested: distance from the nest to a central point in the settlement rookery, the longest foraging trip made during the period of tracking, stable isotope values for both nitrogen and carbon, hatching date of the first chick and the number of chicks alive at the end of February. Results for correlations between pellet types and both foraging strategies and breeding outputs are presented on Table 3. Stable isotope ratios of nitrogen ($\delta_{15}N$) showed a significant negative correlation with the occurrence of prions in pellets (Spearman's rank order correlation; r^s=-0.680, p=0.001, n=24), and significant positive correlations with the occurrence of both eggs and lobster krill in pellets (Spearman's rank order correlation; r^s=0.599, p=0.004, n=21; r^s=0.449, p=0.041 n=24, respectively). For stable isotope ratios of carbon ($\delta_{13}C$), a significant negative correlation was found with pellets with prions (Spearman's rank order correlation; r^s=-0.774, p<0.001, n=24), and a significant positive one with pellets with eggs (Spearman's rank order correlation; r^s=0.521, p=0.015, n=24).

Table 3. Results from Spearman correlations between the frequency of occurrence of various dietary items and several variables related to breeding and foraging performance and strategy. Correlation coefficients and p-values are presented for each case.

Prey types	**Distance from nest to the rookery (n=49)**		**Longest foraging trip (n=21)**		**Hatching date (n=39)**		**Number of chicks alive at the end of February (n=46)**	
	r_s	p	r_s	p	r_s	p	r_s	p
Prions (adults)	0.513	**<0.001**	0.282	0.215	-0.181	0.271	0.111	0.463
Eggs	-0.235	0.104	-0.067	0.774	-0.260	0.110	0.213	0.156
***Lepas* sp.**	0.201	0.167	0.558	**0.009**	0.435	**0.006**	-0.156	0.302
Munida gregaria	-0.368	**0.009**	-0.007	0.975	0.103	0.533	0.115	0.448

Territoriality on feeding grounds

Some skua pairs hold and defend feeding territories in the settlement rookery, chasing off other skuas and caracaras (*Phalcoboenus australis*). From the total of 49 studied pairs, 12 defended feeding territories. These areas were defended by both male and female, but only one member of the pair would be present and actively defending the territory at each time. To determine if the location of the nest influenced which pairs defended territories in the settlement rookery, a t-test was performed to compare the distance from the nest to a central point of the rookery of skuas that defended a rookery territory to skuas that did not defend such feeding territories. The mean distance from the nest to the rookery of pairs not defending feeding territories was of 1473.30(±635.27) (n=37) metres, while the mean distance for pairs defending territories was of 321.92(±198.92) (n=12) metres. This shows that skua pairs who defend feeding territories have their breeding territories closer to the rookery (t-test; t=6.142, p<0.001, n=49).

To assess the impact of this strategy on the breeding success of Falkland skuas, differences between pairs who defended territories and those who did not were tested for both the date of hatching of the first chick and the number of chicks alive at the end of February 2015. On average, pairs of skuas not defending feeding territories had 0.676 (±0.626) chicks alive at the end of February (n=37), while pairs who defended territories had 1.250 (±0.866) chicks alive (n=12). The average number of chicks alive by the end of February showed significant differences between the two groups of skuas (t-test; t=-2.808, p=0.007, df=44). Hatching date did not show significant differences between territorial and non-territorial skua pairs (mean=02/01/2015±; 9 days and 14:14:07; t-test; t=1.664, p=0.105, df=37, n=39).

Breeding success

This breeding season, for the 49 territories sampled, the breeding success of the Falkland skua chicks was of 0.816 (±0.727) chicks per pair. Hatching date was significantly negatively correlated with breeding success (Spearman's rank order correlation; r^s=-0.603, p<0.001, n=39). Breeding success and hatching date showed no significant correlations with the distance from the nest to the rookery (Spearman's rank order correlation; r^s=0.218, p=0.145, n=39; r^s=0.141, p=0.393, n=39, respectively). Isotope ratios seem to be linked with breeding success, since values of $\delta_{15}N$ show a significant positive correlation with the number of chicks alive at the end of February, whereas $\delta_{13}C$ do not (Spearman's rank order correlation; r^s=0.467, p=0.033, n=21; r^s=0.068, p=0.768, n=21, for $\delta_{15}N$ and $\delta_{13}C$, respectively).

Discussion

Diet of Falkland skuas

The use of pellets and food remains has been widely applied in studies of diet for different species of skuas (Phillips *et al*. 1997, Baker & Barbraud 2001, Votier *et al.* 2003, Grilli & Montalti 2012). Pellet analysis is better used to determine and describe diet composition than to quantify the consumption of prey items due to biases (like variable digestion times of different types of prey or variation of number of pellets daily produced) (Malzof & Quintana 2008). They are usually easy to classify to prey type and can be collected with little disturbance to the animals (Votier *et al.* 2003). Prey remains are often used for these studies for the same reasons. These two techniques provide different estimates of prey occurrence since pellets may represent a variable proportion or be constituted by more than one prey item, whereas prey remains usually represent a single carcass. Some bird meals can result in the production of several pellets, making pellets out-number prey remains (Votier *et al.* 2001). At the same time, prey are sometimes eaten at the place of capture, the carcasses not being carried back to the nesting territories of skuas (personal observation). Penguin eggs and prion wings can be found in areas where there are no breeding skuas, although these can be originated by non-breeding skuas or even by other species like the striated caracara (*Phalcoboenus australis*).

During the sampling period, the number of remains collected for this study was larger than the number of pellets. “Beef Point” territories overall had twice as many pellets as found in the “Rookery” area, which may be explained by the fact that “Beef Point” comprises a larger number of territories (n=28, opposed to “Rookery” n=21), but also to the fact that some pairs nesting in “Rookery” territories defend feeding territories in the rookery, and may leave some pellets in these areas instead of their nesting sites. Throughout the entire area sampled, thin-billed prions were the main prey item of the diet of Falkland skuas, which was to be expected since New Island holds the largest population of this small petrel (Catry *et al.* 2003) and different skua species have shown preferences for small and nocturnal petrels before (Mougeot *et al.* 1998, Votier *et al*. 2006). Penguin and blue-eyed shag chicks showed low levels of occurrence in pellet analysis. Since skuas feed only on muscle and soft body parts of these animals, it is natural to assume that they will seldom be shown through pellet analysis (Malzof & Quintana 2008).

When compared, pairs nesting in “Rookery” territories and in “Beef Point” territories show differences in their diet. The distance from the nesting site to the settlement rookery seems to be correlated with the occurrence of thin-billed prions and lobster krill in the diet of Falkland skuas. The territories with the longer distance to the rookery showed higher values of occurrence of thin-billed prions in their pellets. The difference is even clearer when we focus the prey remains, “Beef Point” territories having 14 times more the number of thin-billed prions remains found in “Rookery” territories. This difference between the two areas can be explained by the difference in distances between nesting sites and the rookery. Being an opportunistic feeder, it makes sense that the Falkland skua takes advantage of the closest food sources to their nesting sites. As suggested by Silva *et al.* (2011), it appears that the proximity of nests to the main concentrations of prion burrows influences the diet of Falkland skuas directly, since the nests of “Beef Point” territories are, in comparison, closer to these areas than to the settlement rookery. During the 6 weeks of sampling, each pair was, on average,

responsible for consuming 54.5 prions, which represents an increase of this prey item when compared to previous years (25.5 prions per territory from December to March, Matias 2005). In a previous study on New Island, Falkland skuas were estimated to capture 0.5 prions/day/territory during breeding season (Silva *et al.* 2011). With the results of the present study, it is estimated that the same population of skuas is now capturing on average 1.3 prions/day/territory, this only considering late incubation and chick rearing period (beginning of January till end of February). This population of Falkland skuas was facing a sharp decline in 2011 (Catry *et al.* 2011), which can explain the difference in values of thin-billed prion predation. On the other hand, the breeding success of this population of skuas was higher during this breeding season than in previous years, which may indicate that the population of skuas is growing, justifying a higher level of predation on prions. A study sampling the entire breeding season would be needed to compare these values more objectively.

Fish items had low values of occurrence in the diets of the sampled Falkland skuas, including the individuals that performed foraging trips to the ocean. Therefore, fish does not seem to be an important food item for this species during breeding season.

The performed PCA analysis showed that what dictates the main differences in diet between pairs is the predation of thin-billed prions and the consumption of rookery items (eggs, penguin and cormorant chicks, but mostly lobster krill).

Stable isotopes in blood of Falkland skuas

Stable isotope analysis is another common method to study diets of seabirds. By using this technique, no differences were shown between male and female skuas. This is not surprising since males of these species are known to feed females during incubation and early chick rearing (Furness 1986), and it has been studied before with similar results for other species of skuas (Anderson *et al.* 2009, Phillips *et al.* 2011). When compared between territories, the pairs nesting in “Beef Point” area had lower ratios of both Carbon and Nitrogen than the ones nesting in the “Rookery”. Moreover, the correlation between ratios of stable isotopes and distances between nesting areas and the settlement rookery is also significant. Pairs nesting near the rookery have higher levels of presence of lobster krill in their diets, justifying the higher values of Carbon ratio, which is typically related to a more pelagic diet (Anderson *et al.* 2009). This leads us to conclude that lobster krill is in fact a rookery item, being captured by skuas mostly from other birds regurgitations in the rookery, instead of being captured in the ocean. Ratios of stable isotopes of Nitrogen give us information about the trophic level of the prey items found. Skuas nesting near the settlement rookery feed on rockhopper penguin and blue-eyed shag chicks, prey species with higher values of Nitrogen ratios in their tissues than those found in the major food source of “Beef Point” skuas, the thin-billed prions (Quillfeldt *et al.* 2008, Dehnhard *et al.* 2011, Michalik *et al.* 2013). The isotope signatures of these birds may explain the differences in isotope ratios between the different territories of Falkland skuas of the present study.

Tracking

For the duration of 5 days during late incubation period, 23 skuas of both sexes were tracked with GPS loggers. By analysing the resulting maps, it is possible to say that Falkland skuas are mainly terrestrial

foragers during breeding season, which is in line with what was found by previous studies with brown skuas (Reinhardt *et al.* 2000, Phillips *et al.* 2004, Carneiro *et al.* 2014). The activity of these animals is mostly concentrated during daylight, with some individuals specializing in capturing small petrels during the night (Mougeot *et al.* 1998). During the present study, skuas made on average, 0.9 trips during night time, per individual and during the tracking period. It was to be expected that these trips would happen when these skuas would go hunting prions in the main prion fields but the majority of them were of small movements to bathing areas north and south of the island. Moreover, the occurrence of night movements did not show any correlation with the occurrence of prions in pellets or even with the number of visits to prion fields during the period of tracking. A recent study using GPS loggers in brown skuas on Bird Island showed that although some skuas were active during the night none of them fed exclusively during the night, despite the high abundance of small petrels on the island (Carneiro *et al.* 2014). This appears to indicate that the brown skua population of Bird Island has similar day/night patterns of activity as the Falkland skuas of New Island. This differs from results of previous studies with brown skuas on other sub-Antarctic islands, which showed high levels of activity and petrel predation during the night (Young *et al.* 1988, Moncorps *et al.* 1998, Mougeot *et al.* 1998, Ryan *et al.* 2009).

Falkland skuas showed two main types of foraging trips: terrestrial foraging trips around the island and ocean foraging trips, distancing themselves from their nesting site more than 5 kilometers. The latter ones were rare, skuas being mostly terrestrial foragers during breeding season. This is to be expected since the tracking period corresponded to late incubation period, and terrestrial resources are still available, making the need to forage at sea inexistent (Carneiro *et al.* 2015). From the total sample of 23 tracked individuals, 8 skuas performed foraging trips to the ocean. On average, these lasted 3 hours, a result similar to the recent study of Carneiro *et al.* (2015) with brown skuas. Foraging trips of Falkland skuas to the ocean varied between one and nine hours depending on the birds and on the days. It was to be expected that the main responsible for these long distance foraging movements would be male skuas since females do most of the late incubation period, but from the 8 individuals with these types of trips recorded half were females, one of them distancing itself from the island as far as 20km into the ocean.

Relationship between diet, isotopes and foraging behaviour

The occurrence of thin-billed prions seem to be negatively correlated with the carbon and nitrogen isotope ratios of the sampled birds. At the same time, it shows a positive correlation with the occurrence of both eggs and lobster krill, prey items originated from the settlement rookery and from the ocean.

The occurrence of lobster krill is higher in territories closer to the settlement rookery, hinting that the source of this prey item is the rookery itself (and the regurgitations of the nesting seabirds in the area), opposed to the other plausible option, the ocean. The occurrence of eggs did not show any correlation with the distance to the rookery, although it shows clear differences between territories as shown in Table 1. One explanation for this result is the fact that pellet analysis does not offer a complete representation of diets, and of the consumption of different prey items. Even though the correlation is not significant, there is a tendency in the right direction. Another explanation that might help understand

this result is the fact that the variable refers itself to multiple species (rockhopper penguins, blue-eyed shags and thin-billed prions), as mentioned earlier, including eggs originated from the rookery and originated elsewhere. Goose barnacles were also not correlated with the distance to the rookery. This prey item occurred in 14 territories out of the total sample of 49, but these were spread between "Rookery" and "Beef Point". The 14 pairs of skuas feeding on goose barnacles may have specialized in obtaining this type of food, since these pairs in particular seem to feed mostly on *Lepas sp*., having high levels of occurrence of this item and low levels of occurrence of other prey.

When the occurrence of the main types of prey were correlated with the longest foraging trip flown by the tracked skua pairs, only one variable showed a significant correlation. The occurrence of goose barnacles seems to be linked to the birds that flew the farthest from their nesting site. This is a prey item captured at sea, so it was expected to be more present in diets of skuas who perform foraging movements to the sea. This correlation is interesting because given the short time of tracking of this study (5 days) and the previously mentioned limitations of the used techniques, this expected link is shown in our results, suggesting that our results are accurately informative of the diet of these seabirds.

Hatching date has been proved to be a good indicator of breeding success, the chicks hatching earlier being more likely to fledge (Catry *et al.* 1998, Phillips *et al.* 2004). This variable showed a positive correlation with the occurrence of goose barnacles in pellet analysis, suggesting that this type of food is of poor quality, which is in accordance with previous studies (Furness & Hislop 1981). This could be an indication that individuals specialized in preying on goose barnacles can be occupying a new trophic niche and benefitting from it, although according to previous studies (Matias 2005) Falkland skuas have been more dependent on this prey item for their diet in the past. The difference in occurrences of goose barnacles in skua pellets show that this prey item has been decreasing in their diet, which appears to be compensated with a higher preference for thin-billed prions.

Territoriality on feeding grounds

Skua species are known to occupy and defend feeding territories. In the Antarctic region, they have been observed holding feeding territories, mostly in penguin colonies, defending these areas against competitors (Young 1994, Hahn & Peter 2003). Brown skuas (*Catharacta antarctica lonnbergi*) have more agonistic interactions with non-territorial conspecifics than with other territorial individuals, the former representing the main food competitors (Trivelpiece *et al.* 1980, Mocorps *et al.* 1998), a behaviour also shown by Falkland skuas (personal observation). This species would defend feeding territories within the settlement rookery, occupying nesting areas of not only rockhopper penguins but also black-browed albatrosses and blue-eyed shags. These territories were defended against other Falkland skuas (non-territorial ones) and other competing species like the striated caracara (*Phalcoboenus australis*). Each area was defended by a pair, but only on rare occasions would the two members of the pair be present at the feeding territory. From the total sample of 49 studied pairs, only 12 were observed occupying and actively defending feeding territories (representing 24.5% of the total sampled animals). All territorial pairs had their nesting site close to the settlement rookery, being part of the territories designated as "Rookery". In previous studies it has been shown that skuas nesting in the vicinities of penguin colonies are more likely to hold a feeding territory since this way they are able

to permanently control their feeding territory. (Hahn & Peter 2003). Territory holders must be able to defend both their feeding territories and their offspring at all times, so distance between breeding and feeding territories should be as short as possible.

Territoriality seems to have influence on the breeding success of Falkland skuas, although there were no differences between hatching dates of territorial and non-territorial skuas. Previous studies with brown skuas showed that pairs holding a feeding territory would have earlier hatching dates (Hahn & Peter 2003, Hahn and Bauer 2008, Carneiro *et al.* 2015), but this was not concluded in the present study. On the other hand, territorial pairs of skuas had 1.3 chicks alive at the end of February, while non-terrestrial ones only had 0.7, a higher difference of breeding success than previous studies (Hahn & Peter 2003). This shows that territorial skuas greatly benefit from defending a feeding territory by having a higher breeding success, having an easier access to food at all times, even during the different phases of breeding season, since skuas can feed on eggs, chicks and later on regurgitates from both adults and chicks.

Breeding success

The breeding success of the Falkland skua for this breeding season was of 0.82 chicks per pair, an increase since the last published value of 0.34 from previous years (Catry *et al.* 2011). This previous study revealed that this population was facing a sharp decline, and with the present results of this study it seems that the population is recovering although still showing a lower breeding success than other populations of brown skuas, which often approach or even exceed 1 chick per pair (Furness 1987, Mougeot *et al.* 1998, Phillips *et al.* 2004, Catry *et al.* 2011). As predicted, hatching date showed to be negatively correlated to breeding success, the later the hatching would occur the less likely the chicks would survive long enough to fledge.

The number of chicks alive by the end of February did not show any correlation to any of the main prey items of the diet of skuas, neither with the ratios of stable isotopes of the sampled skuas. This means that the breeding success of Falkland skuas is not dependent on the types of prey they choose to prey on, but most likely on the numbers of prey they can capture. To accurately evaluate the diet of this species and to be able to see its impact on its breeding success, a more thoroughly and exhaustive study would be necessary, to not only identify but also quantify the prey items these animals are dependent on.

A brief comparison with other skua species

Diets of skuas have been studied throughout the years, both in the Arctic and in the Antarctic regions. These studies have been using almost exclusively pellet and prey remains analyses (Moncorps *et al.* 1998, Baker and Barbraud 2001, Votier *et al.* 2003, Malzof & Quintana 2008), and more recently stable isotope analysis (Phillips *et al.* 2007). In sub-Antarctic regions, skuas seem to have more variety in their diets than other populations of the same species breeding in Antarctica, the latter ones relying mainly on penguin colonies (Trivelpiece *et al.* 1980, Mougeot *et al.* 1998). Although generalist feeders, skuas may show some degree of specialization both inter and intra-populations, which seems to be linked to availability of resources (Mougeot *et al.* 1998). This specialization can occur more frequently

with the presence of petrels, being possible that a single species of petrel accounts for more than half of the prey found in pellet and prey remains analyses (Mougeot *et al.* 1998), as it happened with the present study. Brown skuas can show completely different feeding behavior according to their breeding area, some of them relying mostly on burrowing petrels and rabbits (*Oryctolagus cuniculus*), while other populations breeding in different areas of the sub-Antarctic region feed mainly on Antarctic fur seal (*Arctocephalus gazella*) –mostly placentae and carrion-, and to a lesser extent on burrowing petrels (Mougeot *et al.* 1998, Phillips *et al.* 2004, Anderson *et al.* 2009). So it is not surprising that the Falkland skua, being a subspecies of *Catharacta antarctica* shows a different diet from the aforementioned ones.

Diet studies are important since breeding success in skuas is directly linked to food availability and to resource distribution (Mougeot *et al.* 1998). The Falkland skua, being a subspecies that faced a sharp decline on its main breeding population the last decade, may be particularly susceptible to these variables throughout different years. Future studies are recommended on these poorly known subspecies, in order to monitor its demographic parameters and to evaluate how these changes can impact the ecosystem in this important breeding ground for so many seabird that is New Island.

Chapter 4: Final discussion

With the results of this study it was possible to verify that it is not possible to sex Falkland skuas by the use of a discriminant function alone. The best option would be to sex each bird molecularly, or to make direct observations of copulating and/or courtship feeding behaviour along with the use of a discriminant function. Nevertheless, morphometric data about this subspecies was never published, and in the future it can be relevant for comparison studies with other species of skuas. It can even be an important piece of the puzzle that is the phylogeny of the Stercorariidae family.

The breeding success of these seabirds was higher than the one registered on the previous study (Catry et al. 2011), which may indicate that this population is not facing a decline anymore. It would be important to continue monitoring this bird, since it is a top predator on New Island (along with orders birds such as the striated caracara). Predators can exert top-down regulation on ecosystems, acting as key species to regulate and balance the numbers of species of lower trophic levels. Changes in populations of these predators can severly impact the ecosystem, which is why it is important to keep studying them.

Falkland skuas are a poorly known subspecies with close to no studies published about it. The available information about this bird, that recently was facing a sharp decline on its main population (Catry *et al.* 2011), is not enough to establish hypothetical conservation measures, if need be. In an ecosystem like the one on New Island, the constant monitoring of key species can be critical to detect fluctuations on different populations of birds, which can impact in a significant way that same ecosystem in both short and long terms.

The Falklands archipelago is an important breeding ground for many species of birds, many of them endangered. As the fishing industry keeps growing in these parts, the probability of having more birds captured and killed in fishing gear rises. At the same time, the oil industry has many interests in the region, which can, in the long term, be catastrophic to the communities of birds living or breeding in the islands. Having long-term studies and monitoring these populations of birds can help predict changes in their behaviour and in their numbers, making it possible to design and apply conservation measures for the ecosystem of the Falklands that will minimize the impacts of human activities.

From dietary studies of marine birds, valuable information about feeding ecology, foodwebs and oceanographic variablity can be obtained (Barrett *et al.* 2007). At the present moment, there are major concerns when it comes to climate change and fisheries and how these can impact the marine ecology of the oceans, and more specifically, seabirds, by reducing food availability (Furness 2002, 2003, Barrett *et al.* 2007, Wanless *et al.* 2007). Monitoring seabird diets over a series of years can help to determine how diets and feeding behavior vary as a function of fish abundance. While the concern over marine ecosystems being affected by intensive fishing increases, the need to monitor the diets of different seabirds and to, more importantly, incorporate seabird populations into regional models of marine ecosystems is becoming clear (Pauly *et al.* 2005, Barrett *et al.* 2007).

Chapter 5: References

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